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16. ABSTRACT

Since 1972, twelve scientists representing several research disciplines have collaborated in integrated studies to determine the chronic effects of photochemical oxidant air pollutants on a western mixed conifer forest ecosystem. An enormous amount of data has been collected, describing present and past natural conditions of twelve subsystems comprising the conifer forest ecosystems of the San Bernardino Mountains of Southern California. A computer data bank is being developed to allow efficient storage and retrieval of these numerous data sets. The systems simulation modeling process has begun early in 1975. The basic unit for modeling purposes was defined as the forest stand, which may be comprised of from 10 to 200 trees with equivalent land areas of from 100 to 25,000 m^2. Time resolution varies according to the subsystem in question and may be hourly, daily, biweekly, monthly, seasonal, annual, or multi-annual. The subsystems receiving attention at the stand level are defined as: tree population dynamics, oxidant flux canopy response, stand-tree growth, stand moisture dynamics and microclimate, stand mortality responses related to bark beetles and root disease, tree seedling establishment, cone and seed production, litter production, litter decomposition, and small mammal population dynamics.

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PHOTOCHEMICAL OXIDANT AIR POLLUTANT EFFECTS ON A MIXED CONIFER FOREST ECOSYSTEM

A Progress Report

1976

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FOREWORD

Air pollution--including ozone (O_3), nitrous oxides (NO, NO_2), and particularly peroxyacetyl nitrate (PAN)--is placing more and more stress on plant and animal life in southern California. One ecozone affected more strenuously than others is the mixed conifer ecosystem of the San Bernardino National Forest (SBNF), where losses of ponderosa and Jeffrey pines have increased dramatically as pollutant levels in the area have risen. Scientists at the University of California, Berkeley and Riverside, have studied air pollutant effects on 18 plots in the SBNF where data was collected to establish a group of linked models. These models are needed to describe pollutant effects on various subsystems of the ecozone, but also may be used to project conditions and responses in other similar ecosystems, including the Sierra Nevada in northern California and the Wasatch in Utah and the eastern slope of the Rocky Mountains in Colorado. The future importance of the model's description of soils, climate, and vegetation lies in three areas: (1) its predictive capacity; (2) its expected reliability in defining conditions under which stress will be more evident; and (3) its ability to provide researchers with the means to counteract these stresses.

As it now stands, this project has yielded significant data which will allow for further development and refinement of the model. Environmental occurrences during the next two-year period of this grant should help either corroborate or negate projections already generated by the models or inferred by the participating scientists. By enabling scientists to project such future environmental stresses and responses, the models will ultimately enable resource management agencies to move towards controlling those stresses, and to preserving the ecosystems now affected by them.

ABSTRACT

Since 1972, twelve scientists representing several research disciplines -- systems ecology, soils, plant nutrition, forest ecology, forest pathology, wildlife ecology, air pollution technology, and meteorology -- have collaborated in integrated studies to determine the chronic effects of photochemical oxidant air pollutants on a western mixed conifer forest ecosystem. An enormous amount of data has been collected, describing present and past natural conditions of twelve subsystems comprising the conifer forest ecosystems of the San Bernardino Mountains in southern California.

A computer data bank is being developed to allow efficient storage and retrieval of these numerous data sets. The systems simulation modeling process was begun early in 1975. Goals were redefined, a flow paradigm with time-space resolution was developed, and existing simulation models for separate subsystems were considered and adapted when applicable. The basic unit for modeling purposes was defined as the forest stand, which may be comprised of from 10 to 200 trees with equivalent land areas of from 100 to 25,000 m^2. Time resolution varies according to the subsystem in question and may be hourly, daily, biweekly, monthly, seasonal, annual, or multi-annual.

The subsystems receiving attention at the stand level are defined as: tree population dynamics, oxidant flux canopy response, stand-tree growth, stand moisture dynamics and microclimate, stand mortality responses related to bark beetles and root disease, tree seedling establishment, cone and seed production, litter production, litter decomposition, and small mammal population dynamics. Both a flow diagram and a preliminary word model have been prepared to describe the behavior of these linked subsystems.

The most important steps for the immediate future are to make the data management system completely operational, and continue model development and collection of essential data for each subsystem. As the work continues, questions about reversibility or irreversibility of the effects of chronic oxidant exposure and the utility of the output of this research for resource management purposes will be evaluated constantly.

This report was submitted in partial fulfillment of contract numbers 68-03-0273 and 68-03-2442 by the University of California-Riverside under the sponsorship of the U.S. Environmental Protection Agency. This report covers project progress from July 1976 through June 1977. This is a continuing long term study initiated in 1972 with an expected termination date of July 1980.

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LIST OF ABBREVIATIONS AND SYMBOLS

ABBREVIATIONS

SCAB -- South Coast Air Basin
SBNF -- San Bernardino National Forest
CP -- Camp Paivika vegetation plot
BP -- Breezy Point vegetation plot
TUN 2 -- Tunnel 2 vegetation plot
DWA -- Dogwood A vegetation plot
DWB -- Dogwood B vegetation plot
SF -- Sky Forest vegetation plot
UCC -- University Conference Center vegetation plot
COO -- Camp O-Ongo vegetation plot
GVC -- Green Valley Creek vegetation plot
NEGV -- Northeast Green Valley vegetation plot
SV -- Snow Valley vegetation plot
BL -- Bluff Lake vegetation plot
SC -- Sand Canyon vegetation plot
HV -- Holcomb Valley vegetation plot
CA -- Camp Angeles vegetation plot
SCR -- Schneider Creek vegetation plot
BF -- Barton Flats vegetation plot
CAO -- Camp Osceola vegetation plot
HB -- Heart Bar vegetation plot
STANDCMP -- Tree Population Dynamics Computer Routine
TREEGROW -- Tree Growth Computer Routine
SEED -- Cone and Seed Production Computer Routine
ROOTS -- Root Pathogen Dynamics Computer Routine
BEETLE -- Pine Bark Beetle Population Dynamis Computer Routine
CANOPY -- Oxidant Air Pollutant Flux-Canopy Response Computer Routine
WATER -- Stand Moisture Dynamics Computer Routine
MICROCLI -- Microclimate Computer Routine
SEEDLING -- Seedling Establishment Computer Routine
LITTER -- Litter Production Computer Routine
LITDECAY -- Fine Litter Decay Computer Routine
WOODECAY -- Woody Litter Decay Computer Routine
RODENT -- Small Mammal Population Dynamics Computer Routine
PP -- ponderosa pine
JP -- Jeffrey pine
dbh -- diameter at breast height
ppm -- parts per million

SYMBOLS

μg -- microgram O_3 -- ozone

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46	Paul R. Miller and Bill C. Ryan Assisted by H. P. Milligan (deceased) and Robert E. Van Doren U.S. Forest Service, PSW and Maureen A. Thomas	General Description of Ecosystem Properties: Temporal and Spatial Trends of Oxidant Air Pollutant Concentrations

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186	Fields W. Cobb, Jr. Nancy L. Bruhn Staff Research Associate David L. Rowney and J. Richard Parmeter, Jr. Assisted by G. Nick McKibbin Isabel Alvarez A. R. Weinhold Department of Plant Pathology University of California Berkeley, CA and S. K. Sweetwood and Joe R. McBride	Seedling Establishment Subsystem
191	R. F. Luck Assistant Professor of Entomology and Assistant Entomologist Assisted by John Harper Glenn Scriven Marcella Waggoner Division of Biological Control University of California Riverside, CA	Cone and Seed Production Subsystem
204	Rodney J. Arkley Paul J. Gersper and Rudolph Glauser Assisted by John N. Zorich	Litter Production Subsystem
220	J. N. Bruhn Research Assistant and J. Richard Parmeter, Jr.	Foliage Litter Decomposition Subsystem: Microbial Activity and Nutrient Recycling

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226	John M. Wenz Forest Entomologist U.S.D.A., Forest Service State and Private Forestry Forest Insect and Disease Management 630 Sansome St. San Francisco, CA 94111	Foliage Litter Decomposition Subsystem: Micro arthropod Activity
	Donald L. Dahlsten and D. L. Rowney Staf Research Assistant Division of Biological Control University of California Berkeley, CA	
	Assisted by James Barbieri	
233	W. Wayne Wilcox Associate Forest Products Pathologist Associate Professor of Forestry and Nancy D. Oldham Staff Research Associate	Woody Litter Decomposition Subsystem
	Forest Products Laboratory University of California Richmond, CA	
238	Marshall White Associate Research Biologist and Steven K. Sweetwood Bibliographer	Small Mammal Population Dynamics Subsystem
	Department of Forestry and Conservation University of California Berkeley, CA	

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The location of bark beetle infested trees was helped by the constant surveillance of both State Department of Forestry and U.S. Forest Service crews.

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INTRODUCTION

This final report is submitted to the Corvallis Environmental Research Laboratory of the United States Environmental Protection Agency in partial fulfillment of the requirements of EPA Contract number 68-03-0273. The purpose of this report is to describe the forest ecosystem and air pollutant conditions under study and to present research results where they are available. The contract was renewed for each of three successive years from June 15, 1973 through June 15, 1976.

This is a continuing-long term study initiated in 1972 with an expected termination date of July, 1980. The disciplines selected for the investigation were those judged to be the ecosystem components most likely to respond directly to successive pollutant exposures or show secondary response in the complex interacting system. A modeling section was included in the study for the purpose of adapting existing models to the study of pollutant impact on a forest ecosystem and possibly to add a predictive capability to the research.

The San Bernardino National Forest (SBNF) is located at the east end of the 80-mile-long South Coast Air Basin where the last four decades of extensive urban and industrial development have created a severe air pollution problem. Hydrocarbons and oxides of nitrogen generated during combustion of petroleum fuels provided the precursors for ozone and other oxidants. These oxidants, carried by the marine air flow, undoubtedly invaded the forest either when vegetation injury was first recognized in the early 1940's near the coast, or shortly after. Intensity of the pollutant problem and expansion of the affected area has increased markedly as population growth has continued in the basin. Sensitive species in the local National Forest such as ponderosa pine began showing unmistakable injury in the early 1950's.

Green vegetation, including the dominant tree species such as ponderosa pine, are essential elements in the biological community because they are the sole converters of solar energy for use by herbivores, decomposers, and carnivores. Any significant change in the "producer" segment of the ecosystem should be reflected by changes in one or more of the dependent components of that system. An understanding of changes in plant communities suffering from acute, chronic, or insidious air pollutant injury is critical if one is to predict the fate of the ecosystem.

Vegetation in the San Bernardino Mountains is composed about equally of chaparral and forest types. This study has focused on ecosystems in the coniferous forest zones which range from 1200 to 1981 meters on north-facing slopes and from 1524 to 2286 meters on south-facing slopes. Dominant tree species in these areas include ponderosa and Jeffrey pine and white fir. At lower elevations, and particularly on the south slope of the San Bernardino Mountains, the vegetation is largely chaparral. This area is exposed directly to oxidant air pollutants but was excluded from the study not only because its physical and vegetation characteristics were so different from those of the coniferous forest, but also because it is less important for human use.

Eighteen major study plots were selected along an east-to-west gradient of air pollutants (Fig. 1). The highest dosage of air pollutants occurs at the west end near the Cajon pass; the smallest dosage occurs near the eastern border of the National Forest. Smaller plots for specific types of studies were established throughout this area. Uniformity of tree species, soil characteristics, and other physical conditions were important factors considered in locating the major plots.

Soils in the SBNF were generally derived from decomposed granite but texture and depth varied considerably, largely due to the very uneven terrain. Shallow, coarse-textured soils were usually found on the steeper slopes while finer sediments collected in the valleys. Water-holding capacity was generally high and nutrient levels appeared to be adequate for good tree growth. This might be expected since an important criterion for site selection was the presence of a dominant population of ponderosa or Jeffrey pine in areas where ponderosa was not the dominant species.

Forest stand age, structure, and species composition in such a ecosystem are constantly changing and many environmental factors can be expected to accelerate the rate of such change. Since many forest species are susceptible to ozone injury, it is inevitable that heavy dosages of oxidant air pollutants will affect both the rate and direction of plant succession. By developing conceptual models of plant succession and measuring selected vegetation parameters, it may be possible to predict successional patterns when certain environmental variables are known and pollutant conditions have been described. Historical information on vegetation succession following major fires in the past will provide valuable information for such models. Such studies identify variables which influenced the rate and direction of plant succession prior to serious air pollutant conditions and during the decades when oxidant pollutants were increasing rapidly.

Climate is one of the most important factors influencing an ecosystem's essential processes. Climate in the San Bernardino Mountains is distinquished by its Mediterranean character: maximum precipitation (primarily snow) occurs during the cold months, and the summers are warm and dry. Long term weather records available for several sites in the mountains provide valuable data for observing ecological changes induced by periods of unusual weather conditions. Records from each of the major study plots can be compared with historical data from the same general region to assist interpretations of possible pollutant impact.

Since the pollutant problem was identified in the early 1940's,

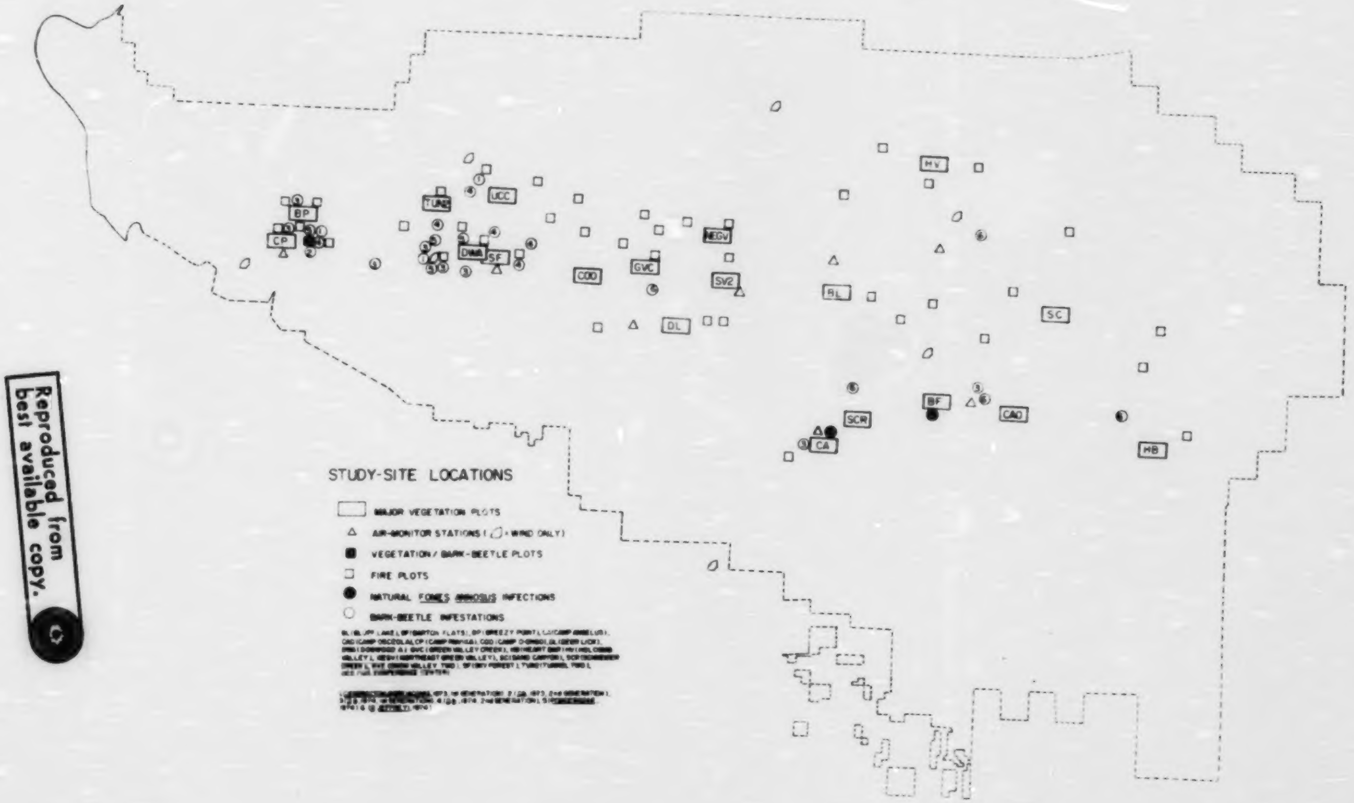

STUDY-SITE LOCATIONS
MAJOR VEGETATION PLOTS
AIR-MONITOR STATIONS (= WIND ONLY)
VEGETATION / BARK-BEETLE PLOTS
FIRE PLOTS
NATURAL FOMES ANNOSUS INFECTIONS
BARK-BEETLE INFESTATIONS
BP
CP
TUNS
UCC
DWA
SF
COD
GVC
NEGV
SV2
DL
RL
HV
SC
SCR
CA
BF
CAO
HB

Figure 1. Location of study plots in the San Bernardino National Forest.

Reproduced from best available copy.

penetration of oxidants eastward through the South Coast Air Basin has been documented by numerous reports of air movement, vegetation injury, and two to three decades of pollutant monitoring by established stations. Intensive studies with airborne instrumentation have verified the penetration of heavily polluted air into this forest. Monitoring stations have been established at selected sites along the pollutant concentration transect to provide accurate information of pollutant exposure for the major study plots.

Oxidant pollutant stress, whether direct or indirect, is expected to have different degrees of effect on the linked subsystems or units comprising the coniferous forest ecosystem. Several investigators selected units of this ecosystem to study a process which may be affected either by the introduction of air pollutants or by significant changes in pollutant dosage. The objective of these various studies focused on ways of applying systems analysis and computer modeling in order to (1) forecast ecological effects of photochemical oxidants in the southern California coniferous forest ecosystem; (2) evaluate the consequences of oxidant pollutants in forest ecosystems on human welfare; and (3) evaluate the adaptability of systems models to other pollutants and other forest types. Process studies of the various ecosystem units are essential to identify and quantify direct oxidant effect and to differentiate between these and biological responses induced by disease, insects, and climate.

A native forest ecosystem is a very complex unit comprised of many interdependent components. Time and funds were not available to study the system in its totality; therefore, various subsystems were selected for study by forest scientists to represent those areas where, in their best judgment, any effect of long-term oxidant air pollutant exposure might be detected and measured. These subsystems included: tree population dynamics, oxidant flux canopy response, stand-tree growth, stand moisture dynamics and microclimate, stand mortality responses related to bark beetles and root disease, tree seedling establishment, cone and seed production, litter production, litter decomposition, and small mammal population dynamics. These have been investigated in relation to such factors as climate (temperature and precipitation), natural topography, and soil types and characteristics. The investigations have led to the collection and storage of a significant amount of data during the four-year period of this EPA grant.

One could hypothesize that an air pollutant's effect on one segment of an ecosystem may be transferred to one or more of the other associated subsystems; in addition, compensatory adjustments may be made within an ecosystem to protect against changes too rapid for the system to handle. With the exception of measurable injury to certain tree and shrub species, the effects of oxidant air pollutants are not obvious, and the subtle effects which could result in major ecological changes over time may ultimately be difficult or impossible to measure completely.

CONCLUSIONS

GENERAL ECOSYSTEM PROPERTIES

Soils

The soil classification is adequate for comparisons of the impact of a range of oxidant air pollutants on vegetation growing on essentially similar sets of soils.

Physical analyses of the soil show that most soils are relatively uniform and low in clay content above the level of contact with decomposed granite substrata. This simplifies the possible comparison of the effect of soils on the relative air pollutant injury to the vegetation. Two soil areas which have more clay in the subsoil have similar soil temperatures but widely differing intensity of air pollutants, so these two are suitable for comparison.

Chemical analyses have shown that the soils over the study area generally contain adequate mineral soil nutrients for plant growth, especially calcium (which is often very low in more humid forested soils). Also, the soils generally contain reasonably high amounts of organic matter and, with few exceptions, contain adequate nitrogen for forest growth. However, only preliminary conclusions can be made about the general relationships between soil nutrient content and oxidant injury to pines.

Vegetation

More variation in forest composition exists than was recognized when the study was initiated. As a result of this variation, comparisons of the impact of oxidant pollutants on forest stands of dissimilar composition may limit the predictive capability of a simple stand succession model.

Climate

An examination of the historical records for precipitation for 24 mountain locations shows large year to year variation and also suggests the strong influence of topography in controlling precipitation. The comparison of the long term precipitation record, now available on computer, with the precipitation record at permanent vegetation plots will be necessary to help separate the effects of moisture and oxidant stresses on stand succession.

Oxidant Air Pollutant Trends

Two of the five meteorological classes describing summer days in the San Bernardino Mountains are most responsible for the highest daily doses of oxidant. These classes include warm-moist and hot-moist days, respectively, and occur more frequently than the remaining classes which include hot-dry, very hot-dry and cool-moist days.

The geometric means for classes 1-5 were 0.03, 0.09, 0.10, 0.09 and 0.06 ppm ozone, respectively for 361 days sampled at Sky Forest in 1974 and 1975.

The wind direction and speed during the hot, dry (Santa Ana wind) day class is the only distinct pattern because winds are from the north and blow toward the source of pollutants. The remaining four day classes are all characterized by winds with a westerly to southerly source, namely, from the origin of photochemical pollutants.

Both large (canyons) and small (hillslope configuration) terrain features influence surface flow patterns and hence the penetration and duration of injurious oxidant doses.

Both increasing elevation of the terrain and dilution during transport were associated with a 68% decrease in the total oxidant dose for June through October between extreme ends of a 37 km, west to east transect in the San Bernardino Mountains in 1974.

Comparison of the hourly and daily average concentrations of ozone, nitrogen dioxide and peroxyacetyl nitrate (PAN) at Sky Forest showed that PAN was frequently present at concentrations injurious to herbaceous plants but nitrogen dioxide was present at concentrations too low to be injurious to plants.

The June through September seasonal oxidant doses from 1968 to 1975 at Rim Forest/Sky Forest have shown large year to year fluctuations caused mainly by the weather of each season. However, the three year moving average has become gradually larger each year since 1972.

SUBSYSTEMS

Definition of the Conifer Forest Ecosystem as a Group of Coupled Ecological Models

Model Development--

Construction of a single flow diagram, incorporating the conceptual models for the various subsystems being investigated, has been a useful step in planning the structure and logic of the computer programs representing each of the subsystems.

With minor changes, it appears very feasible to adapt three simulation models developed in the International Biological Program, Coniferous Forest Biome, to our entire set of models being developed for the study of air pollution effects in the SBNF. Those that we have concluded are readily adaptable include a transpiration simulator, a stand tree growth simulator, and a stand-level hydrology simulator.

Data analysis--

There is an urgent need to implement an easily accessible computer system to store and analyze the various data being acquired within the total research program.

A reliable, computer-based, forecasting procedure for identifying future ecological effects of air pollutants is more likely to be obtained from an explanatory analysis of data on dynamic ecological processes, rather than from data of a descriptive, index-monitoring nature. Therefore, analysis of effects due to oxidant-induced tree crown degradation should reference actual tree crown and foliage properties, rather than a single aggregated smog-injury index.

Model design activity has identified that data needed to be collected on tree growth properties and death rates and their causes, for mature tree communities, tree seedlings, and seeds, so that quantitative relations can be established for computer models.

In order to choose natural aggregations of vegetation plot data for analysis, data need to be obtained on the spatial variation of soil types and hillslope characteristics.

For comparing computer model behavior to the real forests, there is a critical need to evaluate the existence of useable long-term historical data which might already exist in government agency files for the SBNF.

Model Applications and Scope--

With regard to future applications and limits of the simulation models being developed, based on the kinds of data which have already been collected, the models are intended primarily for exploring possible consequences of alternative future air quality levels. This idea is aimed at discovering the effects of controlling an input to the forest ecosystem.

For ecosystem response categories in forest resource-potentials management and hazards management, which are of major concern to the production-oriented land and wildlife management agencies, the basic structure of this set of models is suited for application in recreation management and timber management under various air pollution conditions.

Resource potentials which are not expected to be very directly addressable by these models involve watershed management, forage-livestock management, and wildlife management questions.

In terms of hazards management, the set of models will be addressable to fire, insect pest, and forest disease management questions on a limited scale under air pollution conditions.

Tree Population Dynamics

Fire frequency has been significantly reduced since 1905 in the San Bernardino Mountains. Much of the forest age structure reflects a fire frequency which will no longer influence stand development. Development of the succession model must recognize this change in fire frequency.

The distribution of diameter classes on the permanent plots is skewed toward larger diameter trees. An inadequate number of trees in the 10 to 30 cm DBH size range are available for observation of air pollution injury.

Oxidant Flux - Canopy Response

Conifer Injury/Dose Relationship--

A preliminary oxidant dose - visible needle injury relationship was obtained for current year and one-year old needles of ponderosa pine saplings. Chlorotic mottle symptoms appeared on current needles before they were fully grown and following an accumulated dose ranging between 1.0 and 2.0 x 10^5 $\mu g/m^3$ hrs ozone (excluding background). A more quantitative measure of needle injury effect of different dose sequences and associated weather conditions needs to be incorporated.

The west to east gradient of decreasing chronic injury to ponderosa and Jeffrey pines at 18 vegetation plots corresponds closely with the decreasing oxidant doses measured at 10 air monitoring stations located as close as possible to these plots. The mathematical heterogeneity of the present oxidant injury score system makes it impossible to formulate a valid dose-injury equation.

The oxidant injury score system for ponderosa and Jeffrey pines has provided a useful means for comparing each tree with its former condition at the end of the previous growing season. Among the 18 permanent plots, along the gradient of decreasing oxidant dose the results for 1973 to 1975 indicate that 7 pine populations declined in score (5 significant at $p = .05$, 2 not significant), 5 remained about the same, and 6 increased in score (3 significant at $p = .05$ and 3 not significant). The declining, lower scores (greater injury) were at plot locations receiving the largest seasonal oxidant doses.

Accumulated ponderosa and Jeffrey pine mortality at the 18 plots ranged from 0 to 8.9% between 1973 and 1975. In our score system, where 1 to 36 describes injury ranging from very severe to no visible injury, the mortality greater than 1% occurred in the 12 to 25 segment (severe to slight injury) and involved mainly ponderosa pine.

Mortality that can be related to chronic oxidant injury was not observed among white fir, incense cedar and sugar pine at the 18 plots. White fir was present at 14 of the 18 plots and its scores reflected a gradient of chronic oxidant injury. Incense cedar and sugar pine did not offer a sufficient number of observation locations since they were present at only 5 and 6 plots respectively.

Deciduous Trees--

Black oak was a very useful indicator of the rate of injury development during the season. Because it is present in 13 of the 18 plots, it has helped to characterize the oxidant dose gradient.

Shrubs and Herbs--

Oxidant injury symptoms have been observed on one shrub species and 11 herbaceous species. Injury to herbs may be less severe for those which complete their vegetative and reproductive growth in spring and early summer before the most severe episodes of oxidant pollutants occur.

Stand Tree Growth

Ponderosa Pine Saplings--

The needle, shoot and main stem growth of ponderosa pine saplings maintained in a carbon-filtered air greenhouse compared to an unfiltered greenhouse and ambient outside treatments was dramatically greater following an exposure period lasting from 1968 to 1973. Removal of oxidant stress will allow rapid recovery of ponderosa pine.

Pole-Size Ponderosa Pine--

Oxidant air pollution in the forests of the San Bernardino Mountains reduces the average annual diameter growth of ponderosa pine by approximately 40% in trees under 30 years of age. Merchantable volume growth of trees 30 years of age is reduced by 83% in the zones of highest ozone dose. This reduction in growth, along with air pollutant caused tree mortality, combine to limit production of timber in the San Bernardino Mountains.

Saw Timber-Size Ponderosa Pines--

Annual ring widths of increment cores taken from 160 ponderosa pines, each 30 cm or larger dbh, correlated weakly ($r = 0.51$) with the oxidant injury score of each tree. Other crown characters, e.g. some estimate of foliage surface area, may be a more desirable measure of injury.

The increase of timber volume from low to high risk categories was very large at two Forest Service plots between 1952 and 1972. This is an indirect measure of the consequences of chronic oxidant injury. High risk trees are removed and this procedure may be considered an oxidant-related mortality factor.

Stand Mositure Dynamics and Microclimate

Soil Moisture and Soil Temperature--

The soil moisture regime has been documented for 23 sites beginning in the summer of 1973 to the present and measurements are continuing. Soil moisture depletion is most rapid during June, and the upper 1.5 m of soil is depleted of soil moisture available for plants by about mid-July. However, some moisture at depths up to 2.7 m (9 ft) is used by plants into August. The period of dynamic growth appears to be form May to August, and it appears that air pollutant injury to plants coincides with this period. The total storage capacity of soil moisture available to pine trees in this system is generally considerably higher than the 15 cm often assumed in water balance studies.

Soil temperature regimes at 23 sites have been recorded since mid-summer, 1973. Preliminary analysis of the data suggest that mean annual soil temperatures range from about 4.5 C to 11.5 C in the general study area, with even higher soil temperatures on south facing aspects. Warm and cold sites, dependent upon aspect and slope, can be found throughout the range of air pollutant concentration.

Predawn Xylem Water Potentials--

The seasonal trend in predawn xylem water potential of ponderosa and Jeffrey pines was measured at biweekly intervals at six representative plots. The decrease in water potential (-Bars) varied from plot to plot but generally paralleled the soil moisture depletion curves. Some of the shorter interval variation appears to be related to the daily temperature maximum. These data will be used for an existing transpiration model.

Western Pine Beetle Population Dynamics and Stand Mortality Response

Tree killing beetles pay an important role in the dynamics of a forest community affected by photochemical oxidants. The hastening of tree mortality changes the successional sequences in a plant community and this, in turn, affects many other organisms, some of which have been considered by other investigators in this research program.

Trees in various states of decline due to photochemical oxidants affect various biological attributes of the bark beetle populations. Attack rates and eggs per centimeter of gallery length are reduced by survivorship is greater in diseased trees.

Since there is some evidence that diseased trees have an influence on the dynamics of bark beetle populations, it follows that the rate of tree mortality can be affected and therefore the dynamics of the forest community will be influenced. This is a critical relationship and must be taken into consideration in the development of models of forest communities stressed by photochemical oxidants.

Root Pathogen Infection and Spread-Stand Mortality Response

Observations show that oxidant air pollutants reduce resistance of stumps and tree roots to infection and colonization by the fungus Fomes annosus. Therefore, increased destruction by F. annosus in the San Bernardino Mountains is quite possible, and additional consideration of control measures is recommended.

Tree Seedling Establishment

Influence of Fungi--

Overall populations of soil fungi vary substantially among plots, but differences do not appear to be related to levels of photochemical air pollution.

The traditional damping-off fungi, Rhizoctonia and Pythuim spp, were absent or very rare in the forest soils of the San Bernardino Mountains, but the seeding studies showed that damping-off of seedlings especially in the presence of litter was very common.

Influence of Vertebrates--

Predation by vertebrates appears to account for the greatest loss of seeds, but fungi are responsible for most of the mortality in surviving seeds.

Cone and Seed Production

A greater percentage of ponderosa and Jeffrey pine in the dominant crown class produce cones; codominant ones are the next most frequent bearers. Dominant ponderosa pines represent 33% of the individuals of this species present on the plots, but they account for 63% of the cone-bearing individuals and produce 68% of the cones born by this specie. Similarly, dominant Jeffrey pines comprise only 28% of the individuals of this specie on the plots but account for 58% of the cone bearing individuals and produce 85% of the cones born by this specie.

Litter Production

Variability at Different Study Sites--

The thickness and mass of the forest floor (mainly pine needle litter) was shown to be greater at lower elevations, i.e., the Lake Arrowhead vicinity and at Camp Angelus in the lower Santa Ana Canyon, than at higher elevations. However, forest floor thickness and mass varied even greater between disturbed and undisturbed locations. It was found that thickness of the litter layer was generally markedly reduced where there had been activity such as recreation or logging.

After selective felling of beetle-infested trees of repeated sanitation salvage logging, particularly in the ponderosa pine and ponderosa pine-white fir forest types, the accumulation of heavy fuels from the slash represents a serious wildfire risk which would result in hotter than normal fires.

Pine needles fall, collected on screens under trees during the Fall of 1974, especially in the vicinity of Lake Arrowhead, resulted in comparatively small accumulations under trees that were healthy or only slightly injured by oxidant air pollutants, markedly greater amounts under trees of moderate injury, and levels similar to those of healthy trees under those of severe injury. The latter case reflects the scarcity and small size of needles which remain on the severely injured trees.

The mass and length of individual needle fascicles in litter fall decreases linearly with increasing air pollutant injury to the tree.

Nutrient Input to the Litter in Crown Drip--

The relationship between chemical composition of crown-drip and air pollutant impact on the trees is obscured by variability of crown (foliar) density over the range of impact damage and by variability due to differences in path of intercepted water moving from needles to twigs to large limbs before falling to the ground surface.

The concentration of cations in crown-drip near the trunk of trees averages about 5 times higher than concentrations in precipitation. However, no clear differences in crown-drip concentration obtained between trees varying in air pollutant damage.

Soil Surface Nutrients Under Pines With a Range of Oxidant Injury--
In surface soils with moderate to low organic carbon content there was a trend toward increasing levels of exchangeable calcium, potassium and magnesium under trees as the amount of chronic oxidant injury to pines increased. Further analysis is required to determine the actual correlations of Ca, K, and Mg with organic carbon and nitrogen in surface soils.

Foliage Litter Decomposition-Microbial

Ponderosa pine litter decomposed significantly ($\alpha = .001$) faster than did Jeffrey pine litter. Within each species, decomposition was faster on the site receiving the greatest oxidant air pollution dosage.

Available data suggest that air pollution increased the rate of litter decomposition, but other side influences have not yet been eliminated.

Foliage Litter Decomposition-Microarthropods

Our data gives evidence, although not statistically conclusive, that microarthropod populations decrease under the direct or indirect influence of oxidant air pollution.

Between-plot variations in microarthropod populations tend to be more significant than between tree variations within plots.

Highs of microarthropod density tend to occur in November, coinciding with cooler temperatures and higher moisture.

Species composition appears to be similar to that found in other California forests that have been sampled.

Woody Litter Decomposition

It is probable that wood formed by ponderosa and Jeffrey pines during chronic oxidant exposure does not differ in decay susceptibility since no meaningful differences from wood formed in the absence of pollutants was found in laboratory decay tests.

Small Mammal Population Dynamics

The mixed conifer forest of the San Bernardino Mountains have a well developed fauna of small mammals. This fauna may exert a measurable effect upon the succession of the forests through its collective feeding on seeds and fruits. This effect may be increased indirectly by photochemical air pollution.

Population densities of small mammals appear to be lower on these study sites, particularly on the plots with higher air pollution, than on similar areas in northern California.

Deer mice represent a larger component of the small mammal fauna, and chipmunks and golden-mantled ground squirrels make up a smaller proportion, than is found on similar areas in northern California. The dominance of deer mice results in dramatic fluctuations in the total numbers of small mammals from year to year.

There is much variation in the occurrence of small mammals from plot to plot. Those plots with lower levels of photochemical air pollution generally have a larger and more diverse small mammal fauna. The distribution and abundance of small mammals on the study areas probably correlates most closely with the occurrence and quality of key habitat requirements for vegetation and soil. If these key habitat elements are being affected and/or have been affected by photochemical air pollution, then, in turn, this air pollution will affect indirectly the small mammal populations through this habitat alteration.

The western grey squirrel is abundant and widespread in these study areas. It may have an important effect upon forest succession because of its heavy feeding upon pine and oak seeds.

RECOMMENDATIONS

FOR GUIDANCE OF FUTURE PROJECT ACTIVITIES

Data Collection and Analysis

Soils--

A few more soils will need to be analyzed for chemical and physical properties in order to establish plot parameters. Moreover, considerably more chemical analyses of surface soils will be needed to relate soil nutrient levels to individual trees variously affected by air pollutants.

Due to the natural heterogeneity within many of the 18 permanent vegetation plots, it is recommended that boundaries of soil types, hillslope gradient classes, and hillslope aspect classes be determined in order to allow stratification of plot data for analysis.

Vegetation--

The project should consider a redirection of effort through a focus on a single forest type within the mixed conifer zone. The selection of this type is suggested to be on the basis of the quantity and quality of data already collected and the occurrence of the type relative to the oxidant dose gradient. The final recommendations developed by this project for management prescriptions relating to oxidant-injured stands must be forest type specific.

It is suggested that action be taken to eliminate or resolve the taxonomic discrepancies for ponderosa pine, Jeffrey pine, and Coulter pine trees among several data sets from the 18 permanent plots before tree-related data analysis proceeds.

Climate--

Precipitation should be measured at all 18 permanent plots and three complete telemetering stations should be operated for the full term of the project in order to have a sufficient sample of driving variable data needed for most subsystem models.

Trends in the Annual Oxidant Dose--

Seasonal oxidant doses measured at three permanent stations must be complemented by intermittent measurements at each of the 18 vegetation plots. This will enable more careful estimation of the dose-injury relationship for important tree species.

Measurement of the year to year oxidant dose at the three permanent monitoring stations should be continued for the full term of the project in order to document the variation and the trend in the San Bernardino mountains since 1968 relative to annual climate.

Tree Population Dynamics--

The project research design should be expanded to include determination of tree mortality rates, and the proportion between various causes, on a spatial scale larger than the permanent vegetation plots. This is so the root pathogen and bark beetle submodels can be linked to other models for the forest stand.

The project research design should be expanded to include determination of proportional causes of tree seed and seedling mortality so that a stand regeneration submodel can be quantified and submodels dealing with litter production, decomposition, cone production, and nutrient flows can be integrated with the forest stand modeling program.

A determination must be made of the dynamic importance of various quantities of non-arboreal plant life-forms with regard to the regeneration and growth of various tree species found on the 18 permanent plots.

Investigators in the project should establish several historical data sets. A fire history data file for the 18 permanent vegetation plots should be provided. A determination should be made from various agency files of the availability and reliability of historical data on meteorology, pest-tree damage, stump production, and cone crop production for areas of the SBNF in the vincinity of the 18 permanent plots.

Oxidant Flux-Canopy Response--

A process-oriented analysis should examine the sequence of oxidant concentration exposure in relation to foliar uptake of oxidants controlled by the transpiration process, and the resulting responses of individual properties of foliar injury. This is so we can quantify the tree foliar response to chronic photochemical air pollutant exposure, rather than aggregate all oxidant-sensitive foliar properties into a single numerical value.

The within season development of injury to foliage should be measured biweekly on selected ponderosa pines, Jeffrey pines and black oaks at 6 of the 18 vegetation plots where biweekly measurements of predawn water potential are made.

Stand-Tree Growth--

It is recommended that tree growth data under various levels of oxidant air pollution be collected and analyzed for tuning and validating the tree growth simulator being developed.

Stand-Moisture Dynamics and Microclimate--

It is recommended that soil water characteristics curves be determined at 10°C and 20°C for each soil type in which moisture blocks are being used to monitor seasonal changes in soil water content.

It is recommended that quantitative relations be defined between tree root zone soil water potential and tree xylem water potential. Continuous measurements of temperature and relative humidity must be made at selected vegetation plots in order to provide data to drive the transpiration model.

Western Bark Beetle Population Dynamics and Stand Mortality Response--

Sampling of bark beetle populations should be intensified and should include at least three species of bark beetles and one flatheaded borer.

The interaction of variously diseased trees with bark beetle and wood borer populations should be studied more extensively, noting effects on various phases of the life cycles of the beetles; and also effects on the natural enemies and associates of these tree-killing beetles.

Beetle population data must be linked in some manner to the data on tree mortality from the Forest Service pest damage inventory study. This will help define the apparently critical interaction of smog-damaged trees and tree-killing beetle populations.

Root Pathogen Dynamics and Stand Mortality Response--

Air pollution effects on the epidemiology of other important forest diseases, such as dwarf mistletoe, Armillaria mallea and Elytroderma deformans needle cast, should be investigated.

The influence of pollutants on mycorrhizae could also be significant and should be investigated.

Tree Seedling Establishment--

The factors affecting soil fungus populations are very complex. Detailed studies are necessary to better understand the role of photochemical air pollution on these organisms.

Litter Production--

It is recommended that field data collection on leaf litter production be expanded to include sample trees of all six major tree species found on the 18 permanent plots.

Analysis of the nutrient status of needles falling from trees should, and is, being continued to determine the effect of air pollutants on the needles and, consequently, on the forest floor over time. Nutrient analyses of the foliage will link the litter analyses with the crown-drip studies.

Litter Decomposition--

In order to evaluate trends in fungal populations, fumigation experiments to determine growth rate, spore production and spore germinability should be continued with isolates of common litter decomposing fungi.

One more year of data is required to clarify our current picture of microfloral succession in pine needle decomposition. This will involve sampling of needles on trees prior to litter fall as well as sampling needles separated annually by nylon mesh squares on the forest floor.

Data previously collected should be analyzed further to detect all significant trends. The analysis should attempt to locate changes in species composition of microarthropod populations that may accompany air pollution effects.

Small Mammal Population Dynamics--

Further study of the effects of the collective feeding of mammals on seeds and fruits upon forest succession is needed.

The possible effects of photochemical air pollution upon these feeding and succession relationships, and upon key habitat elements, also need to be investigated.

FOR DESIGN AND MANAGEMENT OF ECOSYSTEM MODELING STUDIES

It is necessary to recognize that some recommendations which arise during the duration of a time-limited research project pertain to conditions which are likely to be more valuable for other subsequent, similar research programs starting anew. The following recommendations fall into that category.

For any full-time research personnel employed under an extramural research grant, the project director should insure that adequate office work space is available so that the personnel can perform the functions for which they were hired.

In any extramural research endeavor like this which involves a number of disciplines, a smaller staff (4 or 5) of full-time senior scientists should be employed, rather than a larger staff of senior scientists who may only be able to devote 5 to 15% of their time. This is especially advisable where the senior scientist's value system forces him to require assistants whose function does not involve interpretation of a scientific data as the research effort approaches its climax.

Any research effort conceived to involve systems analysis and modeling for forecasting purposes should be funded and programmed only in a sequence which involves the systems modeler immediately. A small staff of subject-matter specialists should draw upon a larger pool of professionals on a consultant basis, for the purpose of clearly defining the research problem, identifying the possible kinds of information outputs expectable, the possible users and ways for using the information, and synthesizing the state-of-the knowledge information content from the professional literature into usable computer models. Data weaknesses should thereby be revealed and results of sensitivity analyses on the computer models should be the required justification for prioritizing possible new additional data collection programs.

In any research endeavor where computer technology is planned to be used for data storage, data analysis, and modeling, it is urgently recommended that all of these activities take place from the beginning on the same computer system.

For rapid processing of data not collected by electronic sensing, it is recommended that the use of hand calculators for temporary data storage be evaluated for feasibility and cost-effectiveness.

Where field plots are established to study the effects of an environmental stress, it is strongly suggested that the project director assure that a considerable proportion of the effort and funds be devoted to establishing control plots.

FOR INTERESTED, COOPERATING AGENCIES

The funding agency should recognize and act upon the need of the system modeler to have as clear a definition as possible of the ways in which the funding agency intends to use the information being sought from the research project. It is recommended that the project systems modeler, agency project officer, and other informed agency personnel obtain a conceptual information flow model describing how the environmental information resulting from this research is to be used by administrators and legislators in evaluating secondary standards for photochemical air pollutants.

For efficient execution of research activities, it is recommended that the contract anniversary date be arranged to fall outside of the field data collection season.

The variation in injury scores within each specie on any one plot suggests the possibility of genetically controlled resistance to air pollution injury. The U.S. Forest Service should begin an investigation aimed at the production of air pollution-resistant strains of ponderosa pine from San Bernardino stock.

The U.S. Forest Service should curtail further reforestation efforts with ponderosa pine, Jeffrey pine, or white fir in zone of high oxidant concentration. Programs aimed at utilizing Incense cedar and sugar pine should be developed for these areas.

The EPA should recognize the impact of ozone on plant communities rather than single species when setting secondary air quality standards for forested landscapes.

Studies should be initiated jointly between the U.S. Forest Service and the EPA to investigate the relationship between various silvicultural practices and air pollution injury.

Slash resulting from sanitation salvage logging should be disposed of, possibly by controlled burns. Prescription burning should be incorporated as a part of the sanitation operation. This would reduce the wildfire hazard and should also result in a healthier, more productive ecosystem; air-pollution damage notwithstanding.

Where *Fomes annosus* is present and has potential to cause significant damage, such as in the San Bernardino mountains, control should be initiated through stump protection using substances such as sodium borate.

GENERAL DESCRIPTION OF ECOSYSTEM PROPERTIES: SOILS

Introduction

Geology and Soil Formation in the San Bernardino Mountains--
Soils have formed in the San Bernardino Mountains through the influence of climate, relief, vegetation, parent materials, and time. Climate in this area varies from semi-arid to humid depending on altitude. Parent materials vary from recent alluvium to weathering products of Pre-Cambrian rocks. Igneous, sedimentary, and metamorphic rocks, are the sources of such parent material as well as of alluvium derived from these sources. The types of parent material have influenced the texture, depth, and other properties of the soil found in this area.

The area is composed mainly of gneisses, schists, plutonic rocks, sediments, and recent alluvium. The Cactus granite formation (Miller, 1946), primarily a light-colored quartz monzonite of Mesozoic age, is exposed over a large portion of the mountain area; this esposure is found primarily on the subdued upland surface. Metoamorphosed sedimentary rocks of Paleozoic age are abundant in the area, and numerous intrusions of metoamorphosed rocks are found in both the Cactus formation and other plutonic bodies. Sedimentary rocks of Pliocene and Pleistocene age are also found in the area along with recent alluvium.

The texture of the rocks varies from fine textured volcanics to gravels which contain boulders several feet in diameter. Rocks which have been fractured and broken to a great extent are found in much of the mountain area, especially near faults and in fault zones. In some areas, only normal jointing and fracturing are exhibited by the rocks; the presence or absence of joints and fractures is important to the area's hydrologic characteristics.

The various geologic materials in the San Bernardino Mountains have weathered by physical and chemical processes to form parent materials which have differentiated into soil profiles by the processes of additions, removals, transfers, and transformation. Differences in the rates of these four processes have resulted in the formation of different soil type.

Relief has been an important factor in soil formation in this area. Slopes vary from nearly level to nearly vertical. Soils found on steeply sloping land are generally shallow due to erosion processes during soil formation. Deeper soils are found on more stable landscapes. Most of the soils are coarse textured, well drained, and have a low water-holding capacity. These properties are primarily the result of relief and parent materials.

Relationship of Soils Studies to the Overall Project--

At the organism level, soil moisture and temperature studies have been coordinated with the climate and air pollution monitoring subproject by using identical sites. Litter production, forest-floor measurements, soil sampling and analysis for soil characteristics have been coordinated with sampling sites under specific trees variously impacted by air pollution. These trees were also studied by subprojects dealing with soil and litter arthropords, pathogenic and nonpathogenic fungi, and litter decomposers, plant communities, and the impact of pollutants on vegetation and individual plants.

At the community level, a number of plots are being subjected to intensive study. The pattern of soils and their morphological characteristics are being described, so that they can be related to plant communities, stand composition and growth, and to populations and distributions of small mammals, arthropords, fungi, and other pathogens. Data have been collected on thickness measurements and core mass by which the amount of organic matter (litter) on the forest floor can be estimated over entire plots; however areas disturbed by logging activities have to be separated from essentially undisturbed areas.

At the level of plant succession, we hypothesize that the principal variables affected by oxidant air pollution are: the organic matter content of the soil; the amount, kind, and compositon of litter; and, to a lesser degree, nutrient cycling. Differences in these properties measured at the community and organism level can be applied directly to considerations of plant succession, particularly in relation to seedling germination and survival.

Research Objectives

The research objectives fall under three categories: soils, litter and surface soils, and climate and soil climate.

1) Soils--To analyze the nature and pattern of soil in relation to vegetation patterns and the impact of pollutants on the nature and vigor of that vegetation, especially the western yellow pine trees.

2) Litter and surface soils--To analyze the effects of air pollutants on the litter production, the thickness and nature of the forest floor, and the surface soil below in relation to arthropod and microbial activity and to the suitability of the soil and forest floor as a medium for seedling germination and survival.

3) Climate and soil climate--To analyze the relationship of soil properties, soil moisture and temperature regime, and climate to the susceptibility of vegetation to damage by oxidant air pollutants.

Materials and Methods

Nature and Pattern of Soils--

In relation to the first objective, soils were sampled and described at a number of sites on each of the major vegetation plots and their patterns were identified to give a highly detailed map of each plot. Because of the variability across individual plots, it was necessary to develop the relationships among soil, topography, and vegetation characteristics. Using observed properties of soil color, texture, structure, and reaction (pH), soils on the various plots were classified according to "Soil Taxonomy" (Soil Survey Staff, USDA) and according to soil series names established by the National Cooperative Soil Survey of California. See Appendix A. The soils have been characterized with respect to their chemical and physical properties in order to find relationships between soil properties and the susceptibility of vegetation to air pollutant damage.

Soil properties measured--Particle size distribution (soil texture) was measured because of its importance as an indicator of the soils' ability to store water and nutrients for plant use. Bulk density was measured because of its effect upon root penetration and distribution, and its relationship to soil porosity and permeability to water and air. Exchangeable and soluble cations and soil pH were measured as they relate to the mineral nutrient status of the soils; soil organic matter likewise affects the structure, water retention, and porosity of the surface soil. It is a source of nitrogen for plants and of energy for microorganisms, including pathogens. The water storage capacity of the soil is particularly important in this area because of the long, dry, warm summer during which plants are almost entirely dependent upon stored soil moisture for their survival. Finally, the amount of organic litter (needles and woody material) on the forest floor is related to forest vigor and the production of litter in relation to its decomposition rate. It also directly affects seed germination and seedling survival, as well as soil temperature, moisture, and humus content.

Specific analytical procedures--Exchangeable cations were extracted from soil with ammonium acetate according to Black (1965). Cations from litter samples were prepared using the digestion process recommended by Johnson and Ulrich (1959). Atomic absorption was used to measure the concentration of individual cations. Nitrogen was measured with a modified Kjeldahl analysis from Black (1965), and phosphorus was determined by a colorimetric method (Jackson, 1960). Carbon was determined by a combustion method modified from Black (1965).

Exchangeable and Soluble Cations--

Exchangeable and soluble cations were determined on 22 soils throughout their total depths on the vegetation plots (omitting Camp Angelus, and including two other sites at S22 and NE13) making a total of 251 samples. Soluble cations were determined on a 1:1 water extract of the soil, and exchangeable cations on a neutral 1.0 normal ammonium acetate extract.

Results and Discussion

Soil Classification for the 18 Permanent Study Plots--

Soils were examined at a number of sites in each of 18 plots. The parent material of the soils is partially weathered or decomposed granitic rock on all of these plots except for three which also include alluvial or colluvial material. Sand Canyon (SC) plot is on granitic rock at its eastern end, but the bulk of the plot is colluvium including some marble fragments derived from metamorphic rocks. It is located southeast of Big Bear Lake. Heart Bar plot (HB) is primarily mixed alluvium derived from granitic and metamorphic rocks, and is located in the upper end of Santa Ana Canyon. Camp Angelus plot (CA) is mainly stony granitic colluvium, although the southern end of the plot is formed directly on granitic rock.

Granitic rock weathers first to decomposed granite gruss, then to coarse sand, loamy coarse sand, coarse sandy loam, and eventually to sandy clay loam or clay textured soils if the weathering is sufficiently intense and of long duration. Above about 1800 m (6,000 ft) the mean annual soil temperature is low (less than 8 C) with reduced weathering intensity, so that the soils are mainly coarse sandy loams, or loamy coarse sands without marked accumulation of clay in the subsoil. At lower elevations, soils in moist sites show some degree of clay accumulation in the subsoil. Only on the warmest sites on the desert (north) side of the crest are continuous areas of soils with a sandy clay loam subsoil texture encountered. These plots are Tunnel Two, U.C. Conference Center, (UCC) and Holcomb Valley (HV).

Soils in the Lake Arrowhead region are dominantly of the Shaver series which is dark in color to a depth of greater than 50 cm (Pachic), slightly acid in the surface (Mollic), increasingly acid with depth (Ultic) and with no significant clay accumulation in the subsoil (Haplic). The texture of the subsoil is coarse sandy loam, classified as "coarse loamy"; the clay mineralogy for granitic soils is a mixture of kaolinite, mica, illite, and vermiculite. The mean annual soil temperature is between 8 and 15 C (Mesic), and soils are continuously dry in the upper part for 90 days in summer (Xeric).

Thus, the complete classification of the Shaver soil series is:

Order: Mollisol

Suborder: Xeroll

Great group: Haploxeroll

Subgroup: Pachic Ultic Haploxeroll

Family: Coarse, loamy, mixed, mesic

Soil series: Shaver.

Due to more intense and prolonged weathering on the Tunnel Two and UCC plots soils with distinct subsoil clay accumulation differ in that on Tunnel Two, the surface is dark to a depth of less than 25 cm, while on the other plot it is dark between 25 and 50 cm in depth. Consequently, the Stump Springs soil on Tunnel Two is an Ultic Haploxeralf, while that at the UCC plot is an unnamed soil classified as an Ultic Argixeroll. At HV, north

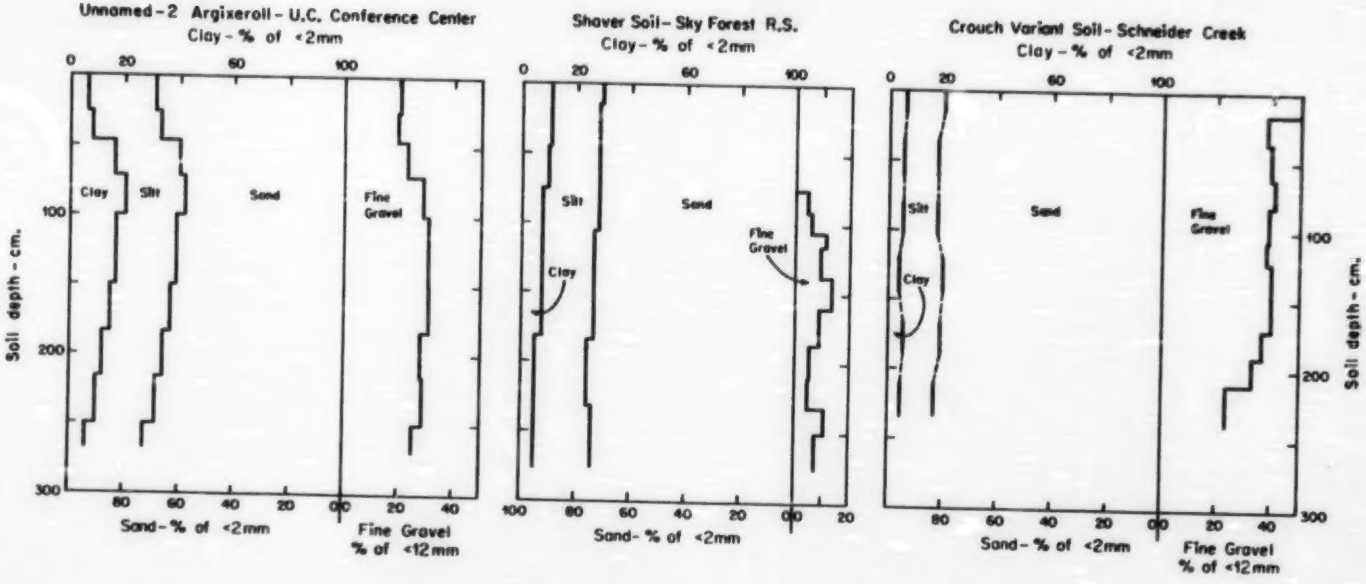


Figure 2. Three representative soil profiles of particle size distribution.

of Big Bear Lake, there are Typic Argixeroll soils of the Domingo Series, similar to those at the UCC, but not increasingly acid with depth.

The remaining soils are either coarse sandy loam ("coarse loamy"), or loamy coarse sand ("sandy") throughout the entire soil depth, except for the Cahto variant soil at CA which is stony, coarse, sandy loam. Some are shallow (lithic) while others are sandy (Psamments). Some have dark, acid surface soils and slightly bleached layers below (Umbrepts) or are not dark (Orthents and Ochrepts). Although Appendix Table A shows that there are some 23 soils represented on these plots, many are quite similar, making it possible to compare the effects of air pollutants of varying concentration on vegetation growing on nearly identical soils in a number of cases.

Chemical and Physical Soil Morphology--

In addition to the soil samples collected at 23 sites, morphological descriptions of soils at 62 sites were obtained on 18 plots. Information included horizon designation, texture, color, pH, and surface structure. Physical and chemical measurements also were made of 23 soils at the soil moisture sensor sites. These included particle size distribution, bulk density, gravel and stone content, pH, exchangeable and soluble cations, and nitrogen and organic carbon content. Only partially complete information could be obtained from the plots at CA, BF, and CO because the stony nature of the soils there essentially precluded volumetric sampling. A total of 246 samples were analyzed in this way. These data provide the basic information for relating the nature of the soil to the kind and amount of vegetation and its susceptibility to air pollution injury.

Particle Size Distribution--

The content of sand, silt, clay, fine gravel, and coarse gravel of selected soil samples from 17 study plots is shown in Appendix B. All values are given in percent of fine soil material, i.e. grams per 100 grams of soil material finer than 2.0 mm in effective diameter. The samples reported include those from the surface soil, a subsoil sample showing the maximum clay content, and a deeper sample of minimum clay content at or near the base of the soil where it grades into decomposed granite.

The variation in particle size distribution with depth for 3 representative soils is shown in Figure 2. The soil labeled "Unnamed-2" has a distinct maximum in clay content at a depth of 70 to 100 cm. Similar soils are found at Tunnel Two and at HV. The Shaver soil found on a number of plots in the Lake Arrowhead area between Camp Paivika and Sky Forest contains less clay and shows only a small and gradual decrease in clay content from the surface downward. The Crouch variant soil at Schneider Creek is representative of the sandier soils at Green Valley Creek, N.E. GV, HB, and SC which contain little clay and considerable fine gravel. The soil at BL is also sandy but contains little fine gravel.

As in most soils formed from granitic rock, these soils generally contain considerable fine gravel (2 to 12 mm in diameter) and, as a consequence, would technically be classified as "gravelly." However, most of the fine gravel is about 2 to 4 mm in diameter and behaves much like very coarse sand in the soil; thus, the "gravelly" designation is omitted from the "coarse sandy loam" and loamy coarse sand" textural classifications (Fig. 3).

Bulk Density of Soils--

The bulk density of volume weight of soils (D_b) was determined in connection with the moisture sampling. The variation of bulk density with depth is shown for eight representative soils in Figure 4. A complete set of data are given in Appendix C.

Of the surface soils, the one at Breezy Point (BP) is the least dense (0.74 gm/cm^3) and very rich in organic matter. The soils with the most dense surface soils are at HV and the UCC with bulk densities of more than 1.4 gm/cm^3, which are soils also having clayey subsoils and are in the warmer north side of the general transects. Most of the soils have surface bulk densities of 1.1 to 1.3 gm/cm^3, and are thus very porous and of good granular or crumb structure.

Subsoil densities are generally from 1.5 to 1.7 gm/cm^3, which is very common for soils of sandy textures. The higher bulk densities are associated with loose sandy soils which tend to crumble into the sampling hole so that those greater than 1.8 gm/cm^3 may well be due to sampling error. Notice that again, BP soil has a low density to considerable depth; this soil also has the highest available water storage capacity as indicated in Appendix C.

Exchangeable and Soluble Cations in Soils--

Results for surface soils are shown in Appendix D. The dominant exchangeable cation is calcium (Ca), with magnesium (Mg), potassium (K), and sodium (Na) decreasing in that order. The values obtained are quite typical of surface soils formed on granitic rocks elsewhere in California (Soil Survey Staff USDA, unpublished document). For example the common range for exchangeable calcium is from 5.0 to 10.0 meg/100 g. Thus, the soils at site 3 on the Dogwood plot (DW-3) and at BL are low in calcium, due to their cold, humid climates. At SC, surface soil is rich in Ca, probably due to its proximity to the ridge above, which contains some marble. Exchangeable potassium content is quite low.

Soluble cations in the surface soil are dominated likewise by Ca followed by K, Mg, and Na in that order. These again are in concentrations often found in granitic soils. All except Sand Canyon site 1 (SC-1) appear to contain adequate supplies of these elements for plant growth.

Exchangeable and soluble cations for representative subsoil layers from the same soils are shown in Appendix E. Again, the soils at DW-3 and BL are low in cations, especially at BL. High values of exchangeable Ca are shown for HV and UCC, both of which have pronounced clay accumulations in the subsoil. A number of the values for exchangeable and soluble K are low (less than 0.1 and less than 0.005 meg/100 gm) respectively. However, the complete data indicate that soluble K is low throughout the entire depth of soil only in Bluff Lake (BL), Sand Canyon site 1 (SC-1), and GVC.

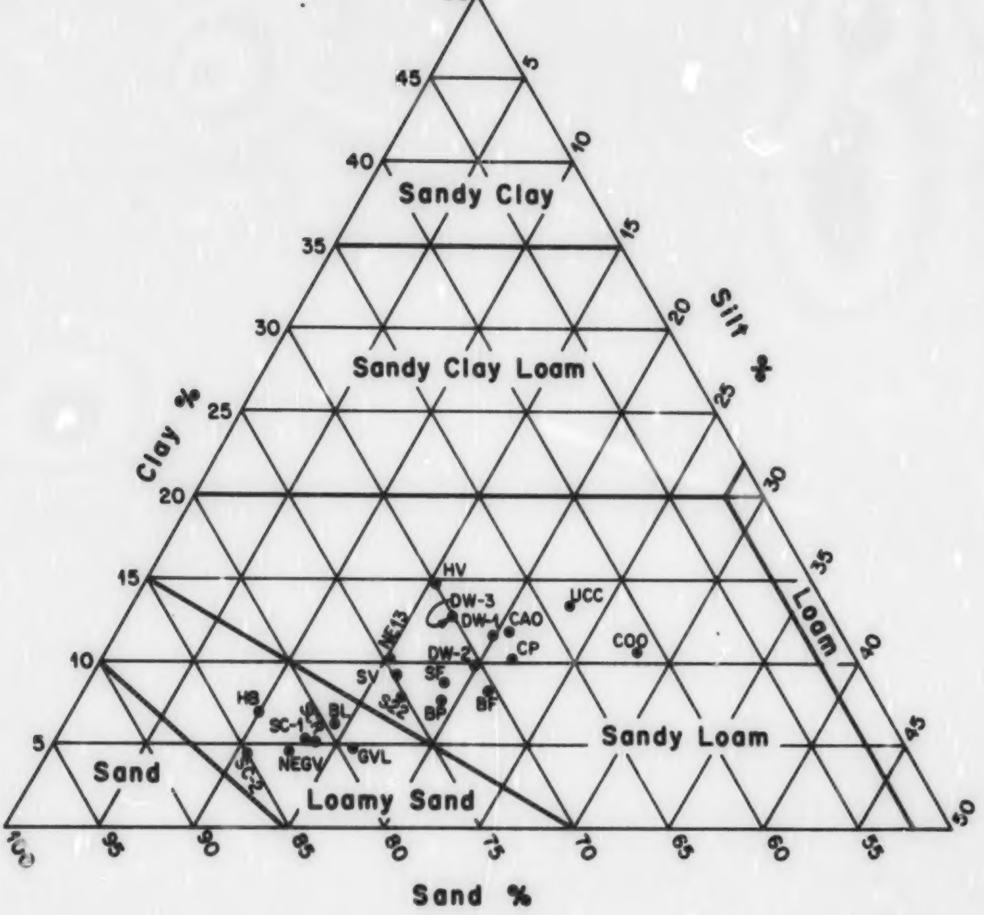


Figure 3. Average particle size distribution of soils of study plots.

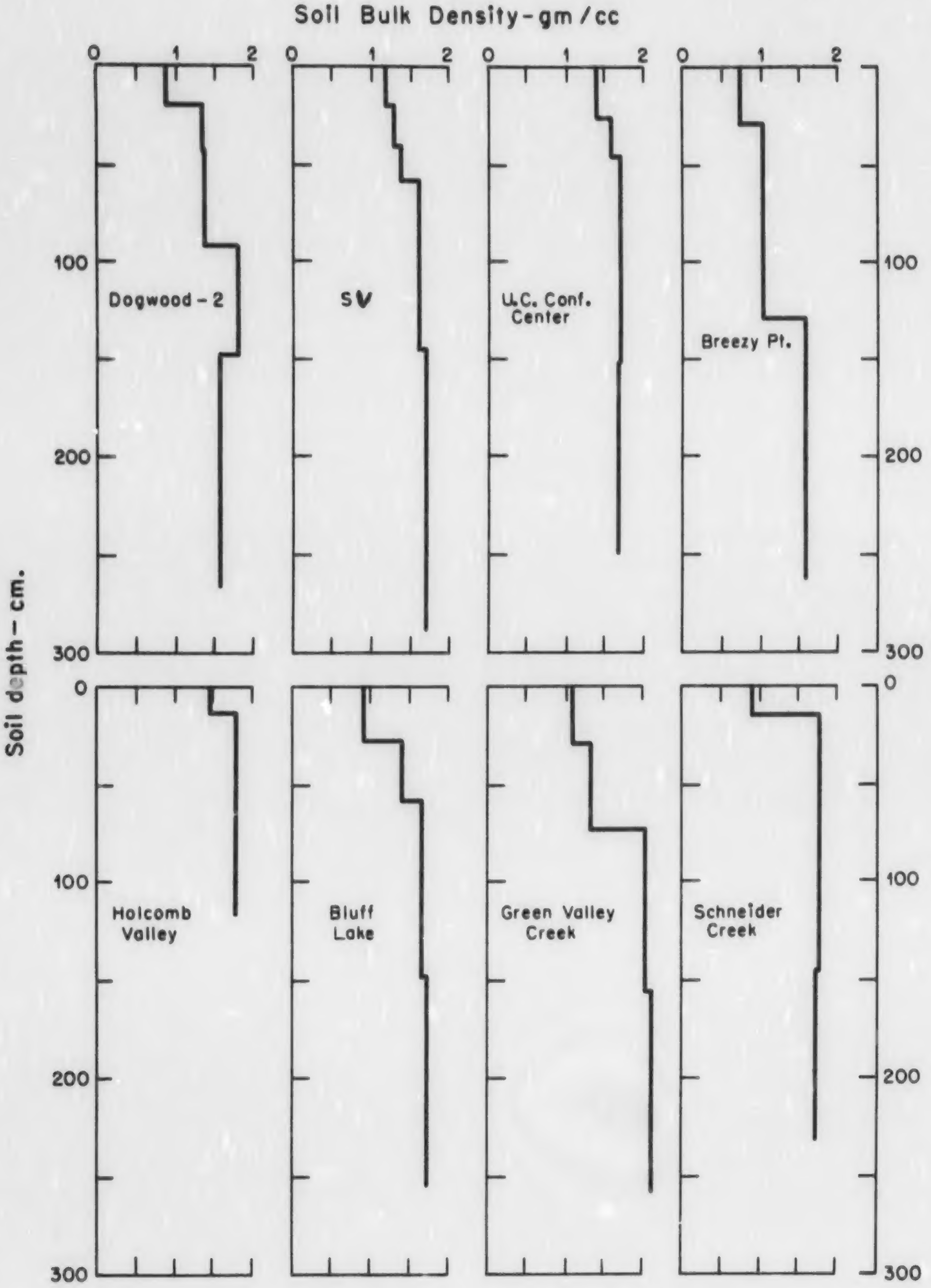


Figure 4. Representative soil bulk density profiles on study plots.

Soil Organic Matter--

Organic carbon and nitrogen were determined on samples from major plots to a depth of 50 or 60 cm. The results for the upper 25 cm of soil only are shown in Appendix F. The soils with the most organic matter are shown to be at DW-3, BL, and BF, with organic carbon values of 2.99 g/100 g or more. Soils with the least organic matter are SC-1, GVC, and HB, all of which have relatively thin needle-litter layers on the soil. The highest value for N was found at Camp O-Ongo, but the unusually low ratio of C to N suggests possible contamination, perhaps from riding horses from the nearby summer camp. Other sites with high N levels are at BL, BF, DW-3 and BP. C/N ratios generally range from 20 to 30, which are common under mixed conifer forests.

Soil Water Available for Vegetation Growth--

In order to quantify the soil moisture regimes in terms of total quantities of water, the soils at the 23 sites were sampled volumetrically for gravimetric measurement of total water content both in April when fully wet, and in October, when they were at minimum moisture content. The difference appears to be the amount of water available to the plants, assuming that the organic litter layer on the surface limits air movement and thus limits direct evaporation from the soil to very low levels. The values obtained by this procedure are shown in Appendix G. Plots included are only those in which soils were sufficiently low in stone and gravel content to permit volumetric sampling. The first 3 columns of data show the volumetric percent and the total calculated depth of available water in April to a uniform depth of 152 cm (5 ft). The last two columns show the total soil depth and the total available water storage. The most significant fact shown by these data is that the available soil moisture storage values within the root zone of the pine forest is very high, about 30 cm,(12 in.or more), compared to the values commonly used in water balance studies of this kind (10 or 15 cm). The low values found for the last five plots listed, may underestimate the water available to the trees, which may be obtaining water from the firm weathered granite below the depth of sampling; perhaps from cracks and joints in the rock.

GENERAL DESCRIPTION OF ECOSYSTEM PROPERTIES: VEGETATION

Introduction

Development of a Conceptual Model for Succession of the Vegetation--

Continued high levels of oxidant air pollutants in the San Bernardino Mountains will affect both the rate and direction of plant succession. Those working with the tree population dynamics subsystem are developing a model of plant succession that can be used to predict species composition and the structure of forest stands subjected to different levels of air pollution. This model will require the cooperation of many of the investigators collecting data on other components of the ecosystem. The first contribution to the development of this model involves the development of (1) a conceptual (non-mathematical) model of plant succession and (2) the field measurement of certain vegetation parameters needed to "run" the mathematical model. The following sections describe some of the important state variables and driving variables of this model.

Vegetation Zones--

The vegetation of the San Bernardino Mountains is composed about equally of chaparral and forest types with important minor elements of woodland, sagebrush, and grassland. Horton (1960) and Minnich *et al.* (1969) have undertaken major treatments of this vegetation. Horton (1960) recognized six vegetation zones on the basis of plant physiognomy and environmental conditions (Fig. 5): chamise-chaparral, woodland-chaparral, desert chaparral, pinyon-juniper woodland, timberland chaparral, and coniferous forest. One or more of these vegetation types occur within each zone. Twenty of these types were defined by Horton (1960) on the basis of field reconnaissance. Using infrared color imagery on aerial photographs, Minnich *et al.* (1969), mapped 28 vegetation types in the San Bernardino Mountains.

Vegetation Types--

Our study focused on the Coniferous Forest Zone, which ranges in elevation from 154 m to 1981 m on north-facing slopes, and 1524 m to 2286 m on south-facing slopes upward to the highest peaks (San Gorgonio, 3,505 m). Four coniferous forest vegetation types were recognized by Horton (1960) in this zone, two of which -- Pine Forest and Ponderosa Pine-White Fir Forest -- were the central concern of this study. An improved map based on a U.S. Forest Service (1973) type map, has been prepared to show the distribution of these types (Fig. 6). Our work indicated that these two general types may be subdivided further into five vegetation types on the basis of species dominance. These types are as follows: Ponderosa Pine Forest, Ponderosa Pine-White Fir Forest, Ponderosa Pine-Jeffrey Pine Forest, Jeffrey Pine Forest, and Jeffrey Pine-White Fir.

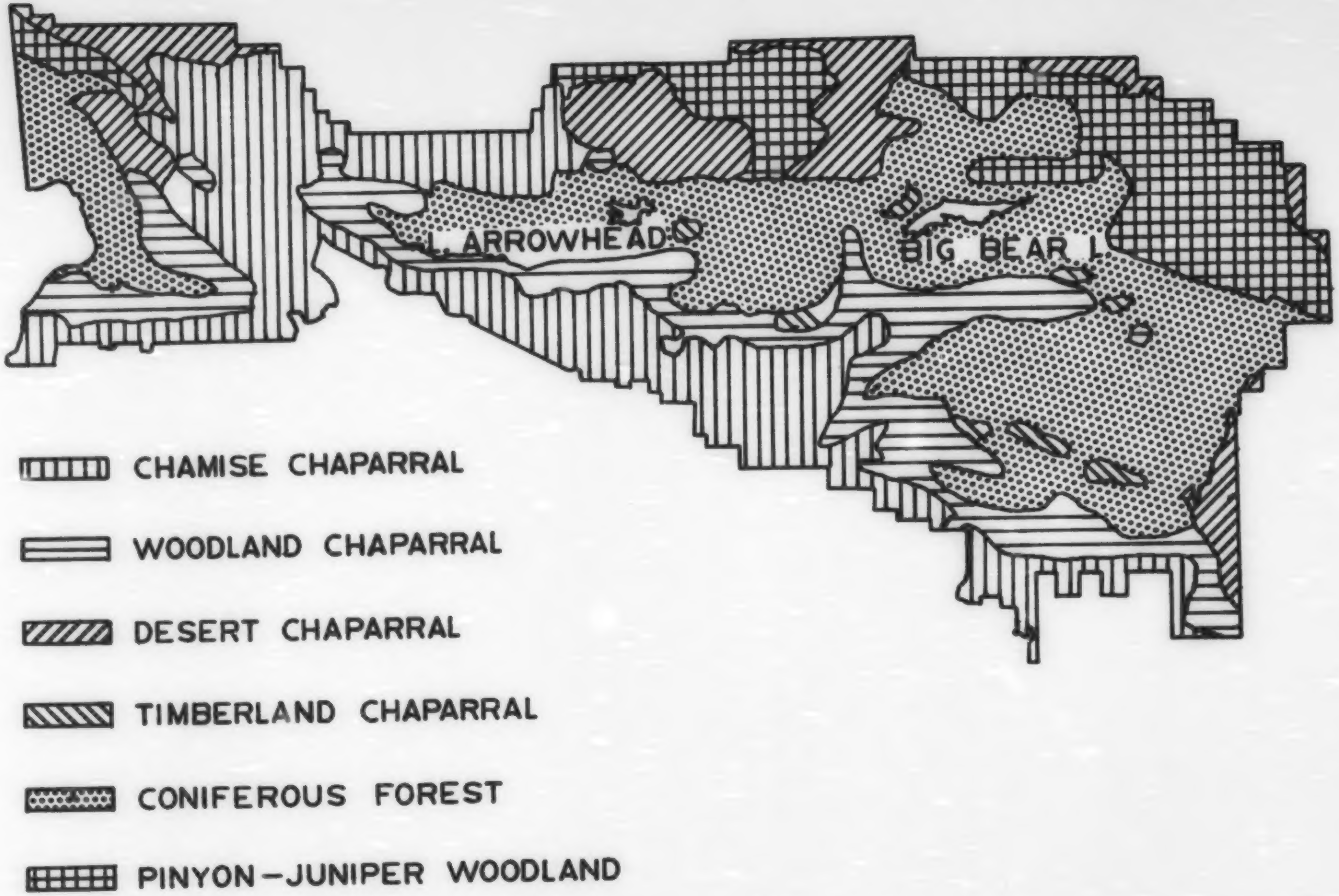

L. ARROWHEAD
BIG BEAR L.
CHAMISE CHAPARRAL
WOODLAND CHAPARRAL
DESERT CHAPARRAL
TIMBERLAND CHAPARRAL
CONIFEROUS FOREST
PINYON—JUNIPER WOODLAND

Figure 5. Vegetation zones of the San Bernardino mountains.

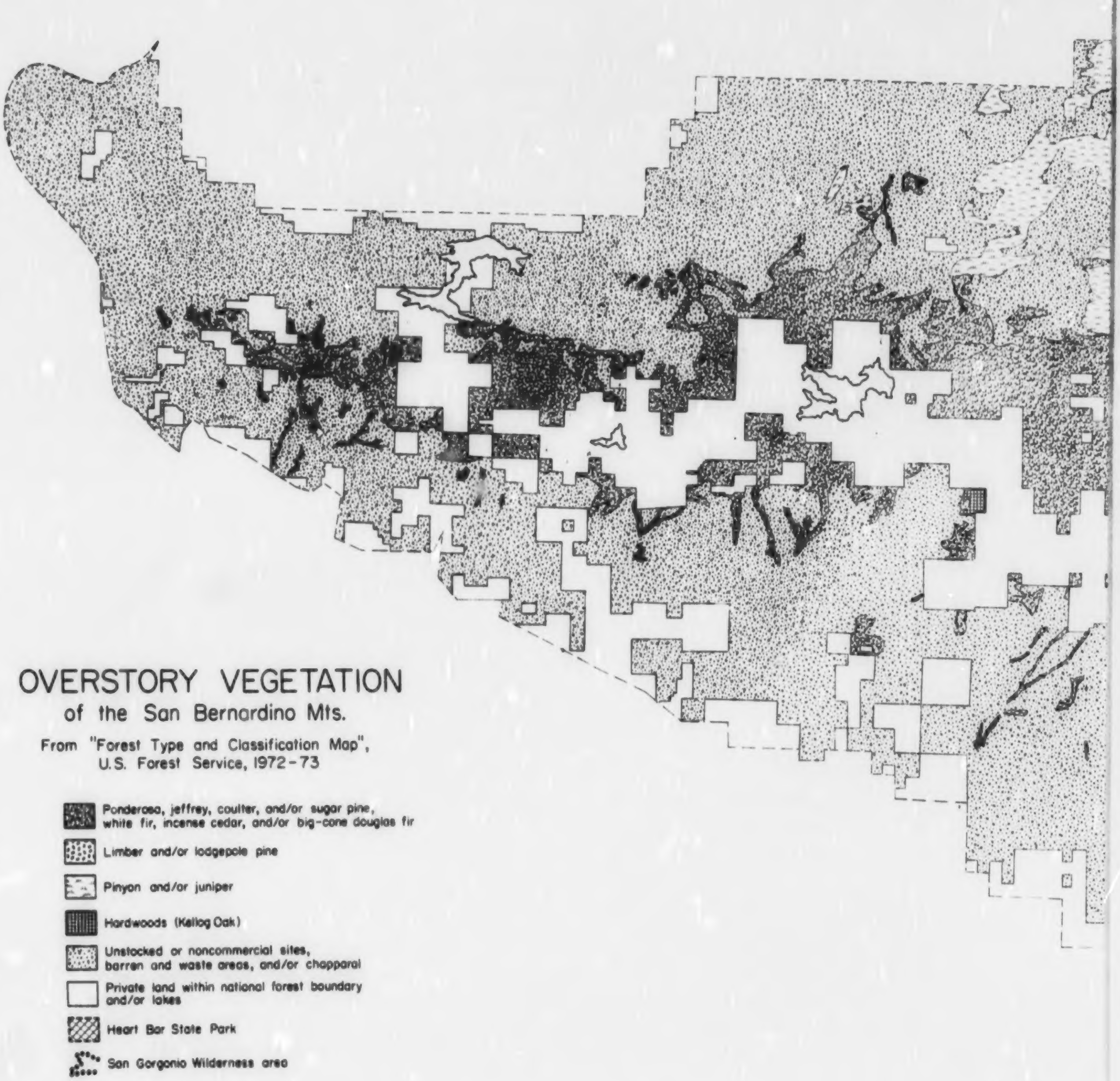
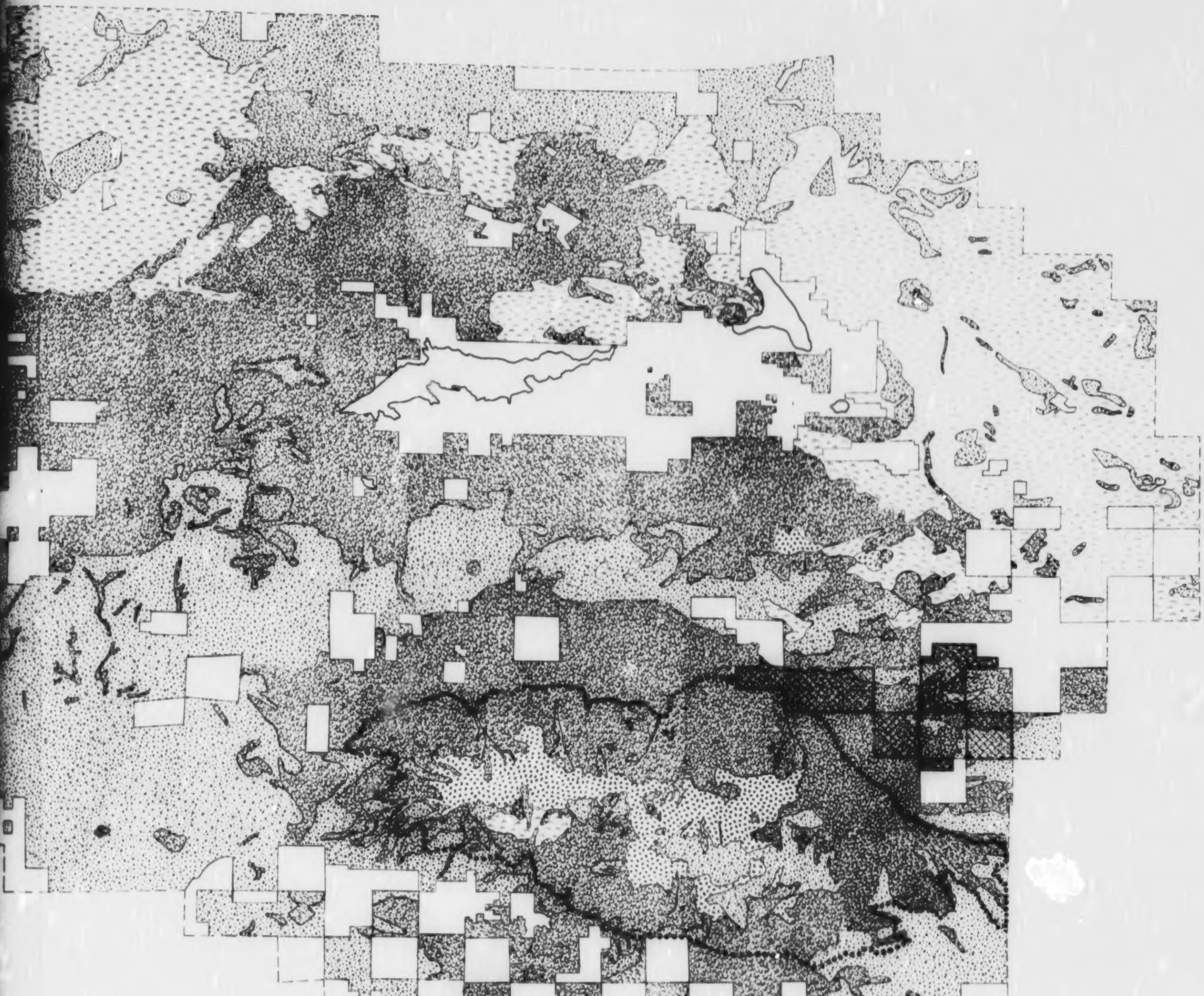

OVERSTORY VEGETATION
of the San Bernardino Mts.
From "Forest Type and Classification Map", U.S. Forest Service, 1972-73
Ponderosa, jeffrey, coulter, and/or sugar pine, white fir, incense cedar, and/or big-cone douglas fir
Limber and/or lodgepole pine
Pinyon and/or juniper
Hardwoods (Kellog Oak)
Unstocked or noncommercial sites, barren and waste areas, and/or chapparal
Private land within national forest boundary and/or lakes
Heart Bar State Park
San Gorgonio Wilderness area

Figure 6. Overstory vegetation type map of the San Bernardi



ardino Mountains.

Forest vegetation types dominated by ponderosa pine are distributed mainly in the western half of the San Bernardino Mountains, while Jeffrey pine-dominated types occur more frequently in the eastern half (Fig. 7).

Materials and Methods

Study Plots Within Vegetation Types Along a Gradient of Decreasing Oxidant Dose--

The vegetation subcommittee participated in establishing 18 permanent study plots in the San Bernardino Mountains (Fig. 1); a nineteenth study plot (Deerlick) was added recently, but results presented in this report refer only to the first eighteen plots. The first criterion for the selection of plot locations was species composition. Stands were selected in which either ponderosa or Jeffrey pine was dominant. Additional selection criteria included tree size, topographic position, parent material, and position along the oxidant gradient (Taylor, 1974). The decriptive characteristics of the vegetation on these plots have been analyzed by the vegetation subcommittee and are reported in a following section.

Heterogeneity of the Ponderosa Pine-White Fir Type on Adjacent Sites With Different Aspects--

Sampling fire history--The date of the last major fire on each plot was determined from basal fire scars on trees in or adjacent to the plots. Quadrant and line interception methods, identical to those used to characterize the vegetation on the 18 permanent plots, were used to measure the vegetation. The age of each tree on the plot was also determined by ring counts.

Results and Discussion

Tree Layer in the 18 Permanent Vegetation Plots--

Five plots, each representing one forest type, are summarized in Table 1. Species composition in the tree layer of each plot is illustrated in Figure 8. The Camp Paivika plot is typical of the Ponderosa Pine Forest type; ponderosa pine comprises 57.9% of the plot. Black oak is a species common to the Ponderosa Pine Forest, and makes up 41.6% of the tree composition at Camp Paivika. The Ponderosa Pine-White Fir Forest type occurs at the Sky Forest plot, where ponderosa pine makes up 46.9% of the tree composition, and white fir contributes 30.2%. Other tree species on the Sky Forest plot include sugar pine, incense cedar, black oak, and dogwood. The Barton Flats plot is representative of the Ponderosa Pine-Jeffrey Pine Forest type. Ponderosa pine contributes 55.9% of the tree composition of the plot while Jeffrey pine contributes 34.5%. The remaining 9.6% is made up of black oak and interior live oak. The Jeffrey Pine-White Fir Forest type occurs on the Green Valley Creek plot where 19% of the trees are Jeffrey pine and 30.3% are white fir. Other species occurring on the Green Valley Creek plot are sugar pine, incense cedar, black oak, and interior live oak. The Jeffrey Pine Forest type is well developed on the Snow Valley plot, where Jeffrey pine make up 96.2% of the tree composition.

Shrub Layer in the 18 Permanent Vegetation Plots--

The vegetation on each of 18 permanent plots can be described further

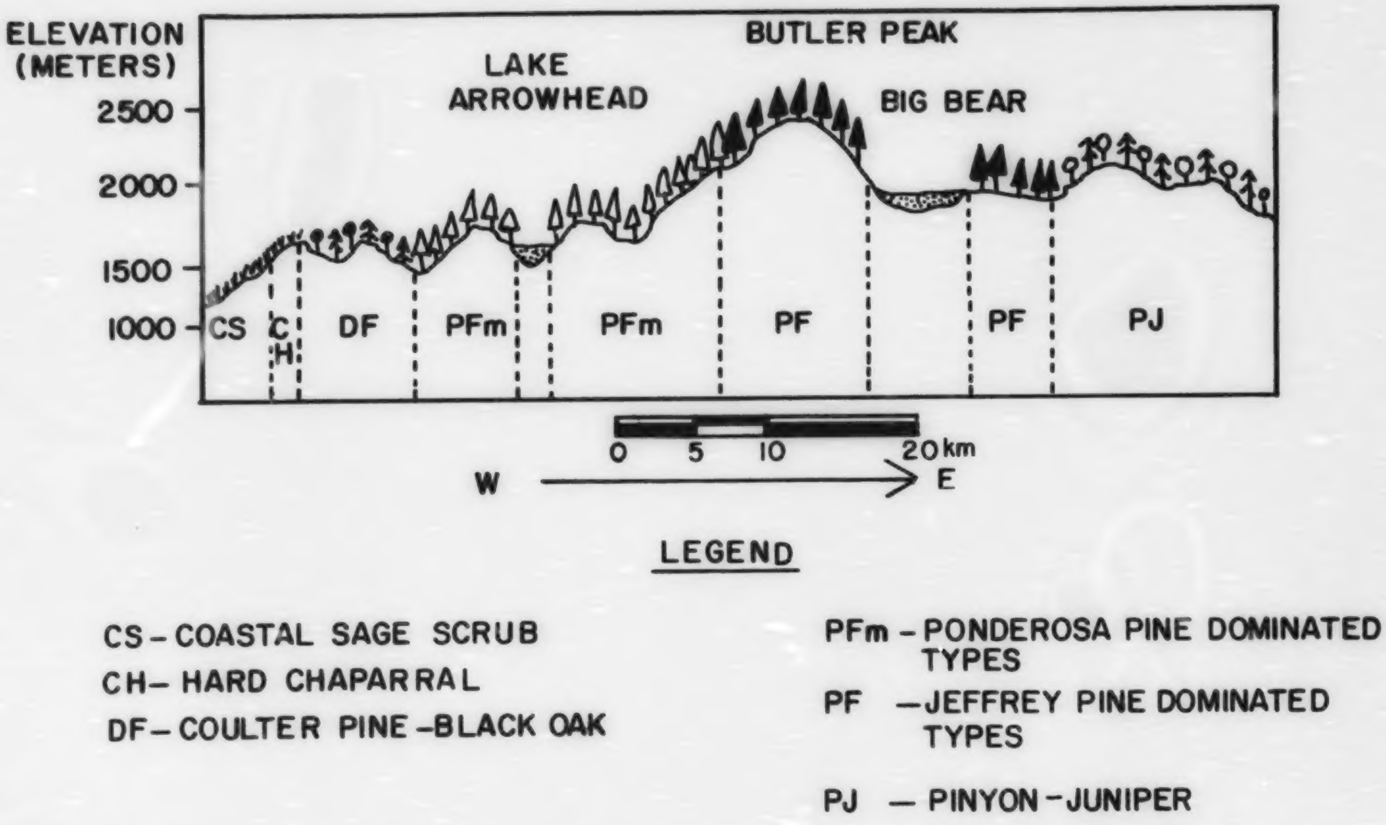

ELEVATION (METERS)
2500
2000
1500
1000
LAKE ARROWHEAD
BUTLER PEAK
BIG BEAR
CS
CH
DF
PFm
PFm
PF
PF
PJ
0
5
10
20km
W
E
LEGEND
CS - COASTAL SAGE SCRUB
CH - HARD CHAPARRAL
DF - COULTER PINE - BLACK OAK
PFm - PONDEROSA PINE DOMINATED TYPES
PF - JEFFREY PINE DOMINATED TYPES
PJ - PINYON - JUNIPER

Figure 7. East-West distribution of vegetation types in the San Bernardino Mountains.

TABLE 1. TREE LAYER DATA FROM PLOTS REPRESENTATIVE OF EACH VEGETATION TYPE DOMINATED BY PONDEROSA OR JEFFREY PINE IN THE SAN BERNARDINO MOUNTAINS.

	Characteristics			
Mixed conifer forest types[*]	No. of trees[†]	Spp. comp.[‡]	Density[§]	Basal area[‖]
Ponderosa Pine (N.W. Paivika)				
PP	98	57.9	217.8	24.11
SP	1	0.5	2.2	0.03
IC	--	--	--	--
WF	--	--	--	--
JP	--	--	--	--
BO	70	41.6	155.6	6.32
QW	--	--	--	--
DW	--	--	--	--
Total	169	100	375.6	30.46
Ponderosa Pine - White Fir (Sky Forest)				
PP	104	46.9	144.4	28.38
SP	15	6.8	20.8	0.60
IC	25	11.2	34.7	4.10
WF	67	30.2	93.1	3.85
JP	--	--	--	--
BO	7	3.1	9.7	2.21
QW	--	--	--	--
DW	4	1.8	5.6	--
Total	222	100	308.3	39.14
Ponderosa Pine - Jeffrey Pine (Barton Flats)				
PP	139	55.9	200.1	16.87
SP	--	--	--	--
IC	--	--	--	--
WF	--	--	--	--
JP	86	34.5	123.8	10.21
BO	16	6.4	23.0	5.99
QW	8	3.2	11.6	0.56
DW	--	--	--	--
Total	249	100	358.5	33.63

TABLE 1. TREE LAYER DATA FROM PLOTS REPRESENTATIVE OF EACH VEGETATION TYPE DOMINATED BY PONDEROSA OR JEFFREY PINE IN THE SAN BERNARDINO MOUNTAINS. (CONTINUED)

Mixed conifer forest types[*]	Characteristics			
	No. of trees[+]	Spp. comp.[‡]	Density[§]	Basal area[#]
Jeffrey Pine - White Fir (Green Valley Cr.)				
PP	--	--	--	--
SP	11	5.4	12.2	2.93
IC	10	4.9	11.1	1.63
WF	62	30.3	68.9	4.94
JP	39	19.0	43.3	12.20
BO	82	40.0	91.1	4.70
QW	1	0.4	1.1	0.02
DW	--	--	--	--
Total	205	100	227.7	26.42
Jeffrey Pine (Snow Valley)				
PP	--	--	--	--
SP	--	--	--	--
IC	--	--	--	--
WF	3	2.9	3.9	1.30
JP	99	96.2	129.4	21.56
BO	1	0.9	1.3	0.16
QW	--	--	--	--
DW	--	--	--	--
Total	103	100	134.6	23.02

TABLE LEGEND:

[*]Symbol	Common Name	Scientific Name
PP	ponderosa pine	*Pinus ponderosa*
SP	sugar pine	*Pinus lambertiana*
IC	incense cedar	*Libocedrus decurrens*
WF	white fir	*Abies concolor*
JP	Jeffrey pine	*Pinus jeffreyii*
BO	black oak	*Quercus kelloggii*
QW	interior live oak	*Quercus wislizenii*
DW	dogwood	*Cornus nuttallii*

[+] Number of trees on the plot

[‡] Percent of species composition on the basis of number of trees

[§] Number of trees/hectare

[#] Basal area in square meters/hectare

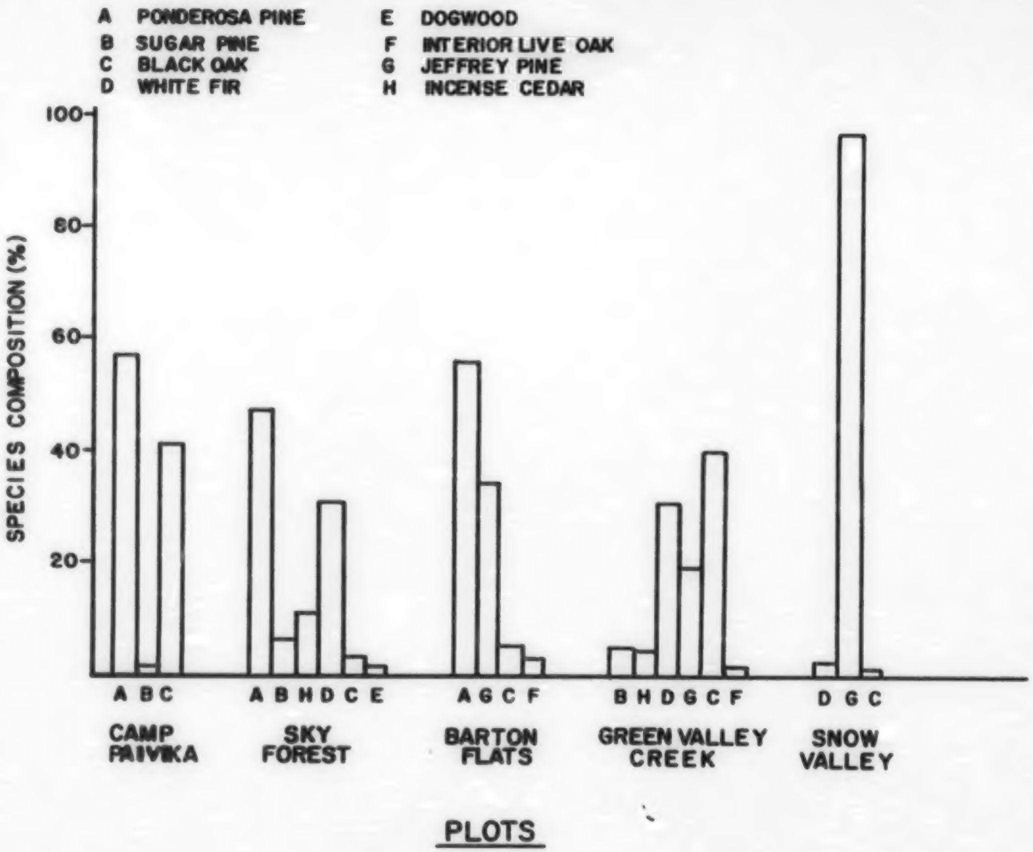


Figure 8. Tree species composition of five permanent plots.

in terms of the characteristics of the shrub and herb layers. The plots occurring in forest types dominated by ponderosa pine have an average shrub cover of 3.8%, while those plots occurring in forest types dominated by Jeffrey pine average 26% shrub cover. Arctostaphylos pringlei and Ribes roezlü are typical of the shrub layer in ponderosa pine-dominated types. Ceanothus cordulatus, Arctostaphylos patula, and Artemisia tridentata are common shrubs in forest types dominated by Jeffrey pine (See Fig. 29).

Heterogeneity of the Ponderosa Pine-White Fir Type on Adjacent Sites with Different Aspects--

Fire history--A meaningful conceptual model of forest succession requires a study of plant succession following fire in the ponderosa- and Jeffrey pine-dominated forest types in the San Bernardino Mountains. This study identifies variables which have influenced the rate and direction of plant succession in the past. In the summer of 1974, eighty-three plots were established in this study (Fig. 1). Analysis of the field data suggests that a stratification of fire succession plots according to physiographic units is necessary before meaningful successional patterns can be determined. General observations made during the previous field seasons suggest that fire has been a selective factor in forests of mixed species composition. White fir and incense cedar are more vulnerable to wildfire than are pine species. Similar observations have been made in other parts of California (Biswell, 1977) and the southwest (Weaver, 1964). Other mortality factors operating in the San Bernardino Mountains, including air pollution, are also selective. Any model of plant succession must take into account the rate at which these mortality factors remove trees from a forest stand. Since mortality rates differ according to the age of plants, it is necessary to know the age structure of the stand. With knowledge of (1) the initial age structure, (2) expected mortality rates from various factors (insects, pathogens, air pollutants, fire, herbivores), and (3) reproductive rates (seed production and establishment), one could approach the modeling of plant succession using a modification of the life table method introduced by Leak (1970). With this approach in mind, we included a study of age structure of stands in the San Bernardino Mountains as one of our research objectives. Initially, the age structure of the 18 permanent plots was determined using ring counts on cores taken with increment borers. Tree age was also determined on the 83 fire-succession plots. These data, along with additional samples to be taken in the next field season, will build an important data source for use in the modeling of plant succession.

Four patterns of forest regeneration have been identified from the age structure curves of the 18 permanent plots. In order of increasing occurrence, these are:

1. No significant tree regeneration over the last 20 years;
2. Regeneration of Ponderosa or Jeffrey Pine;
3. Regeneration of more tolerant conifers;
4. Invasion of Black oak.

The occurrence of any pattern is independent of air pollution gradients in the forest; however, the selective impact of air pollution on tree mortality, combined with certain of the above patterns of regeneration, may have serious consequences for the continued dominance of pine in certain parts of the San Bernardino Mountains.

Multiple Uses of Vegetation Composition Data--

The descriptive information developed by the vegetation subcommittee has been used by other investigators for the selection of sampling locations, general habitat descriptions, and as a basis for comparison with auxiliary plots. Several auxiliary plots were established to study bark beetle population dynamics; these plots were surveyed by the vegetation subcommittee using the same procedures used on the permanent plots. This type of survey allows certain comparisons with other data collected on the permanent plots.

GENERAL DESCRIPTION OF ECOSYSTEM PROPERTIES: CLIMATE

Introduction

Temporal and Spatial Trends of Temperature and Precipitation--

The climate of the San Bernardino Mountains is distinguished by its Mediterranean character, with maximum precipitation during the cold months (November to April) and minimum precipitation during the warm summer months (June, July and August). Only 1% of the world (and no other part of the United States) has this particular climate. Deep snow may cover the mountain peaks during the winter but only rarely does any remnant of snow cover persist on higher peaks through the summer. A peculiar feature of the precipitation is the occurrence in July and August of sporadic thunderstorms which originate over the desert and reach their maximum development mainly over the eastern one third of the mountains. Precipitation ranges from light to heavy over short distances and usually for short periods during the afternoon hours.

The annual fluctuations of temperature and precipitation exercise strong controls over most ecosystem processes under study by this project. The objectives of this section are to:

1. Examine the long term temperature and precipitation record at representative sites.

2. Compare the short term precipitation record at the permanent vegetation plots with long established precipitation stations.

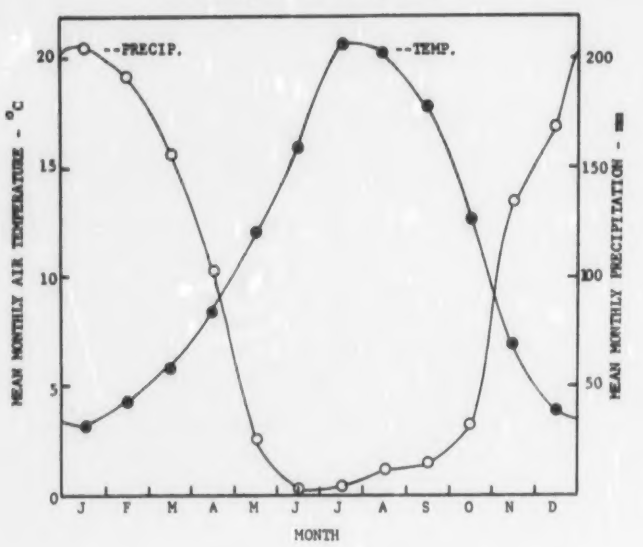
Materials and Methods

Long term records for temperature and precipitation were obtained from the National Weather Service and the San Bernardino County Flood Control District. Winter precipitation was collected at vegetation plots using Sacramento type storage gauges precharged with antifreeze and a small amount of transmission fluid. Changes from the initial fluid depth in each gauge were measured with a dip stick at the end of each month. Summer precipitation was collected with small plastic rain gauges with a 9 inch capacity.

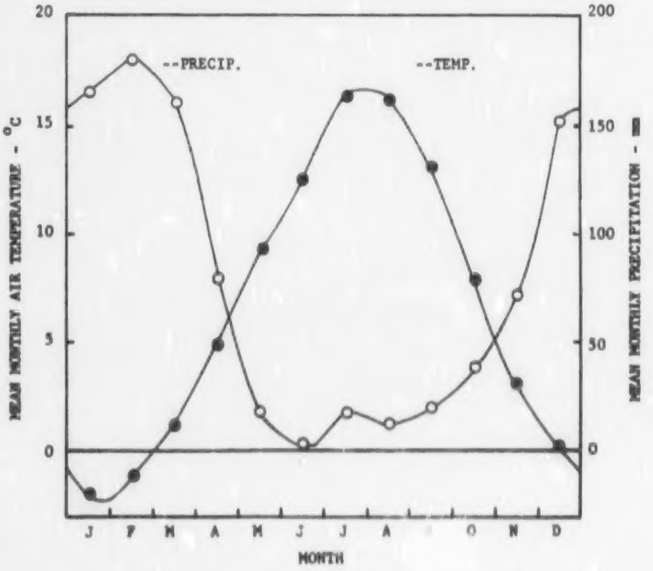
Results and Discussion

Long Term Temperature and Precipitation at Lake Arrowhead and Big Bear Lake Dam--

The relationship between mean monthly precipitation and temperature is illustrated in Figure 9 using long-term Weather Bureau records for



LAKE ARROWHEAD, LONG-TERM MEANS.



BIG BEAR LAKE DAM, LONG-TERM MEANS.

Figure 9. Long-term Weather Bureau records for monthly means of temperature and precipitation at Lake Arrowhead and Big Bear Lake Dam.

Lake Arrowhead and Big Bear Lake Dam. Although Big Bear Lake is higher (Elev. 2,078 m) and colder (mean annual air temperature, 6.43 C) than Lake Arrowhead (Elev. 1,587 m and mean annual air temperature, 11.05 C), it receives less average annual precipitation (934 mm) than Lake Arrowhead (1063 mm).

Precipitation Record Comparisons Showing Trends Relating to Topography--

The mean annual precipitation measured or projected for a number of stations maintained by the San Bernardino Flood Control District is shown in Table 2 in relation to nearby study plots and their elevations. In Appendix H, these tables give the monthly and annual means, standard deviations, standard errors of the means, and coefficients of variation for each of 24 precipitation stations in the San Bernardino Mountains. These stations are in close proximity to the 18 permanent vegetation plots shown in Figure 10.

A comparison of the elevations of the precipitation stations to the elevations of the permanent vegetation plots is shown in Table 3. The mean annual precipitation does not increase uniformly with elevation in the area because of the configuration of the mountains and its effect upon the movement of air masses and subsequent occurrence of rain showers. The long-term precipitation estimates indicate that the plots near Lake Arrowhead (DWA, UCC, and SF) receive the greatest precipitation, while those at the eastern end of the study area receive the least (HB and SC). However, two years of data collected with snow storage gauges at each plot (Table 4) indicate that Holcomb Valley north of Big Bear Lake receives low precipitation, while the Bluff Lake north of Big Bear Lake on a high plateau area receives more precipitation than any other plot. The long-term means shown in Table 2 may be compared with 1973-1974, and 1974-1975 precipitation measured at each vegetation plot (Table 4). An improved precipitation map for the SBNF can now be constructed from these data.

Precipitation variability across the transect of study plots might have implications for the degree of oxidant injury to vegetation. Analysis of this possible interaction is reported in the Stand Moisture Subsystem section.

TABLE 2. COMPARISON OF MEASURED AND PROJECTED MEAN ANNUAL PRECIPITATION FROM SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT STATIONS NEARBY THE PERMANENT VEGETATION STUDY PLOTS.

Station	Elev.	Nearest major vegetation plots	Direction and distance (km) of station from major vegetation plot	Mean annual precip. (mm)	Years of record
Cedar Pines Park	1448	CP	1.6 N	579[*]	6
Job's Peak	1573	BP	1.5 W	707[*]	7
Blue Jay Co. Yard	1646	DWA	1.0 NNW	1073[*]	4
Lake Arrowhead	1587	UCC	1.6 S	1063	35
Arrowhead RS	1705	SF	0	1112[*]	13
Running Springs	1854	COO	3.2 SE	960	21
Green Valley Lake	2098	NEGV	1.6 WSW	829[+]	6
		GVC	2.4 ENE		
Big Bear Lake Dam	2078	BL	2.4 N	934	33
Big Bear Lake Fire Station	2056	HV	5.2 S	570	24
Big Bear City	2073	SC	6.4 N	301[‡]	13
Green Canyon Springs	2134	SC	2.4 E	331[‡]	10
Heart Bar	2039	HB	0	389[‡]	7
Camp Angelus	1762	CA	0	750[‡]	5

[*] Long term mean projected from Lake Arrowhead by linear regression

[+] Long term mean projected from Running Springs by linear regression

[‡] Long term mean projected from Big Bear Lake Fire Station by linear regression

Correlation coefficients for linear regression are highly significant with values at least 0.92, where 1.0 represents a perfect correlation.

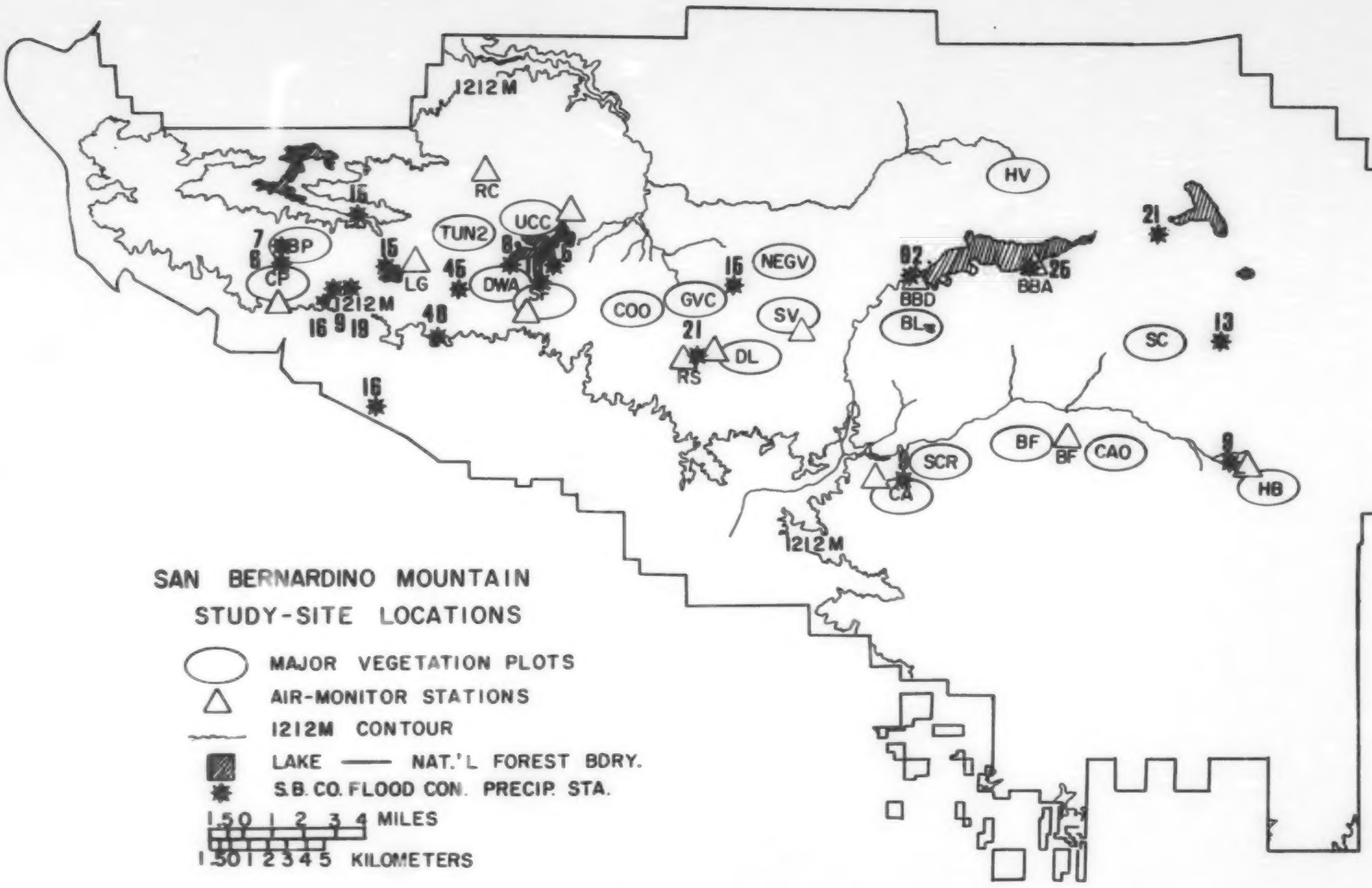

SAN BERNARDINO MOUNTAIN
STUDY-SITE LOCATIONS
MAJOR VEGETATION PLOTS
AIR-MONITOR STATIONS
1212M CONTOUR
LAKE
NAT.'L FOREST BDRY.
S.B. CO. FLOOD CON. PRECIP. STA.
1.50 1 2 3 4 MILES
1.50 1 2 3 4 5 KILOMETERS
1212M
RC
TUN2
UCC
BP
CP
LG
DWA
COO
GVC
NEGV
SV
RS
DL
HV
BBD
BL
BBA
SC
SCR
CA
BF
CAO
HB
7
6
15
16
9
19
45
48
8
21
92
25
13

Figure 10. Locations of San Bernardino County Flood Control District precipitation stations in the San Bernardino Mountains in relation to major vegetation study plots and air monitoring stations.

TABLE 3. COMPARATIVE ELEVATIONS OF 18 PERMANENT VEGETATION PLOTS WITH PRECIPITATION COLLECTORS AND THE SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT PRECIPITATION STATIONS.

Elevation meters (above m.s.l.)	Plot name	District station name and length of record (years)
1120		Pilot Rock Conserv. Camp (16)
1150		Panorama Point (17)
1385		Lake Gregory (16)
1450		Cedar Pines Park (6)*
1485		Crestline Fire #2 (10)
1500		Crestline County Yard (14)
1525	Breezy Point	
1545		Job's Peak (6)*
1550		Crestline SE (20)
1555		Lake Arrowhead FD 4 (6)
1595		Squirrel Inn #1 (73)*
1600	Camp Paivika	Lake Arrowhead Fire (84)
1610	Univ. Calif. Conference Cen.	
1650		Blue Jay County Yard (4)*
1655	Tunnel Two Ridge	
1705		Arrowhead Ranger Station (17)
1720	Sky Forest	
1725	Dogwood	
1730		Squirrel Inn #2 (46)
1787		Camp Angelus Spencer (9)
1830	Camp Angelus	
1853	Schneider Creek	
1855		Running Springs (21)*
1900	Camp O'Ongo	
	Deer Lick	
	Barton Flats	
1950	Green Valley Creek	
2040		Heart Bar State Park (10)
2055		Big Bear Lake Fire (26)
2075		Big Bear City (21)
2080		Big Bear Lake Dam (93)
2100		Green Valley Lake (16)
2135	Camp Osceola	
2160	Heart Bar	
2170	N.E. Green Valley	
2225	Holcomb Valley	
2320	Bluff Lake	Green Canyon Springs (13)
2365	Sand Canyon	

*Record not continuing

TABLE 4. WINTER PRECIPITATION, 1973-1974, AND 1974-1975, AT EACH MAJOR VEGETATION PLOT, SAN BERNARDINO NATIONAL FOREST, DETERMINED BY SNOW STORAGE GAUGES, SEPTEMBER 15 TO MAY 1.

Plot	Precipitation* (cm)		Precipitation* (inches)	
	1973-1974	1974-1975	1973-1974	1974-1975
CP	45.6	48.5	18.0	19.1
BP	99.0	76.9	39.0	30.3
TUN 2	85.6	64.1	33.7	25.2
UCC	80.8	49.4	31.8	19.4
DWA	--	83.6	--	32.9
SF	106.9	79.5	42.1	31.3
COO	81.1	68.5	31.9	27.0
GVC	71.8	59.3	28.3	23.3
NEGV	73.3	54.8	28.9	21.5
SV	77.0	--	30.3	--
DL	--	78.2	--	30.8
HV	39.7	30.8	15.6	12.1
BL	134.8[+]	68.9	53.1[+]	27.1
SC	35.1	31.1	13.8	12.2
CA	38.6	61.6	15.2	24.2
SCR	39.5	47.2	15.6	18.6
BF	40.1	40.9	15.8	16.1
CAO	43.1	35.1	17.0	13.8
HB	37.8	32.9	14.9	12.6

[*] All data calculated by formula using individual snow gauge dimensions.

[+] Apparently much too large, snow probably drifted over the snow gauge.

GENERAL DESCRIPTION OF ECOSYSTEM PROPERTIES: TEMPORAL AND SPATIAL TRENDS OF OXIDANT AIR POLLUTANT CONCENTRATIONS

Introduction

Climate and Oxidant Concentrations--

The National Primary and Secondary Air Quality Standards for Photochemical Oxidants (California Air Resources Board, 1974), Appendix I, provides the basis for evaluating the trends of pollutant concentrations in the area under study. Penetration of photochemical oxidant pollution eastward from the Los Angeles metropolitan area to the inland valleys and mountains has been recorded for many years at surface stations operated by both the California Air Resources Board and various county agencies. Data back to 1963 are available from the downtown San Bernardino station operated by the County Air Pollution Control District (APCD). The accuracy of the long-term records has been examined by Pitts, et al. (1976). The mechanisms of oxidant transport have been described for sample days by simultaneous use of surface and air borne oxidant sensors (Blumenthal, et al., 1974; Edinger, et al., 1972). The dependency of ozone concentration on the elements of the regional climate is illustrated by the simple models of Tiao, et al. (1976), and Zeldin (1975), which are used to predict maximum ozone concentrations for the following day. McCutchan and Schroeder (1973) have used a stepwise discriminant analysis of eight meteorological variables to classify days from May through September in southern California, specifically around the San Bernardino mountains. A description of the five resultant day-classes appears in Table 5; three of these classes (2, 3, and 4) are associated with elevated ozone concentrations.

This study of the chronic effects of oxidant air pollutants on the mixed conifer forest requires a means of documenting the daily oxidant dose and associated meteorological conditions. The within-season distribution or occurrence of these five meteorological patterns is superimposed on two other factors: (1) the declining availability of typical soil moisture as the summer season passes in a Mediterranean climate, and (2) the state of plant growth or phenological development. A given distribution of meteorological patterns associated with high oxidant concentrations occurring within a growing season is expected to result in variable amounts of injury to individual species in the forest community. The most important use of this method for classifying meteorological patterns in our pollutant effects study is to provide a means for comparing both prevailing day-to-day patterns within a summer season and those between summer seasons. Later, these comparisons include the ozone doses associated with each day class or most frequent sequences of day classes. Then it will be possible to obtain better

TABLE 5. DESCRIPTIONS OF METEOROLOGIC PATTERNS FOR FIVE CLASSES OF SPRING AND SUMMER DAYS IN SOUTHERN CALIFORNIA.*

		Associated synoptic pattern	
Class	General weather	Surface	500 mg
1	Hot, dry continental air throughout the day (Santa Ana)	Large high pressure over Great Basin	Strong northerly sinds over area with trough east of the area
2	Relatively dry forenoon; modified marine air in afternoon; very hot (heat wave)	High pressure over Great Basin and thermal trough over desert	Subtropical closed high over area
3	Moist, modified marine air; hot in afternoon	Thermal trough over desert	Ridge over area
4	Moist, modified marine air; warm in afternoon	Thermal trough over desert	Trough over area
5	Cool moist, deep marine air throughout the day	Synoptic low over desert	Deep trough or closed low over area

*Source: McCutchan and Schroeder (1973).

resolution of the dose-environment interactions which characterize each season, and to compare this characterization with the amount of injury to forest vegetation both during and after the season.

Research Objective

The objectives of this program of air monitoring and measuring meteorological variables are:

1) To examine the relationship of cumulative seasonal ozone dose to meteorological patterns at three telemetering stations;

2) To examine the relationship of surface wind flow to pollutant transport;

3) To define the gradient of oxidant across the study area in terms of cumulative seasonal dose at six stations complementing the three telemetering stations;

4) To compare the simultaneous concentratons of ozone, total oxidant, PAN, and NO_2 on an hourly and daily basis;

5) To examine the historical trends of seasonal oxidant doses.

Materials and Methods

Equipment and Calibration Methods--

Meteorological--The remote stations at Camp Paivika, Sky Forest, and Barton Flats, all of which were part of a Forest Fire Meteorology Research Network (McCutchan, 1975), measure temperature at 0.5 m and 1.2 m, relative humidity at 1.2 m, wind speed and wind direction at 9.2 m, and net radiation at 0.2 m above the ground. The stations accept hourly interrogations from the master station, convert analogue measurements to digital form, and transmit data either directly or through a repeater back to the master station.

Each remote station consists of: (1) a modular field data system (Ball Brothers Research Corporation Model 700); (2) a 4.5-watt two channel VHF band radio transceiver which is manually switchable (General Electric Model PR-36-RCC-66) with attenna (Phelps Dodge Model 130-509); (3) a 12-VDC rechargeable battery; (4) RAMOS hat-type radiation shields for temperature and relative humidity sensors; and (5) meteorological sensors and signal conditioners.

The master stations consists of: (1) a minicomputer (Data General Noval 1200) with 24 K core memory, real time clock, power fail option, and auto program load option; (2) an ASR 33 teletype; (3) a nine track tape transport (Wangco); a station clock registering days, hours, and minutes (Chrono-Log); (4) a modem (Intertel Model 2026); and (5) a remote control for voice transmission to remote stations (General Electric Model 549-AISI).

Sensors were calibrated over their entire range in 10% increments.

Supplementary wind data was obtained with a portable station (Meteorological Research Incorporated Model 1072-2); additional temperature and relative humidity data was obtained with hygrothermographs (Weather Measure Model H302). Meteorological data is stored on magnetic tape or punch cards and has been summarized monthly on an hourly basis (see Appendix J)

Air pollution--At the telemetering stations at Camp Paivika, Sky Forest, and Barton Flats, ozone was measured with ultraviolet photometers (DASIBI Model 1003AH). Strip chart recorders were used to back up data stored on magnetic tape. Total oxidant was measured at all other stations by the Mast Model 724-2 and data was recorded on strip charts. The strip chart records from both DASIBI and Mast instruments were key punched and summarized by the hour for each month. Nitrogen dioxide and peroxyacetyl nitrate (PAN) were measured at Sky Forest only. Nitrogen dioxide was measured continuously, using Saltzman's reagent, with an Air Monitor IV (Technicon Instrument Corporation). PAN was measured at 15 min intervals by an automated Panalyzer 681 (Varian) with an electron capture detector.

Total oxidant data gathered prior to June, 1975, was based on the former primary standard calibration procedure using buffered potassium iodide. A recent revision (California ir Resources Board, DeMore Committee, 1974) for calibration of ozone sensing instruments suggested that a correction of all hourly ozone concentration data could be made by a multiplication factor of 0.80. The former primary standard calibration procedure, using buffered potassium iodide, was found to be 20% higher than ultraviolet photometry, which has now been accepted as a valid primary (transfer) standard in California. Thus, when total oxidant and ozone data for 1973 and 1974 appears separately all values should be approximately 20% less than indicated. However, where total oxidant records for all years between 1968 and 1976 are compared, they have all been corrected to correspond to the new calibration standard. The altitude correction factor was calculated by dividing the larger pressure height (mb) at the calibration laboratory by the smaller pressure height at each mountain station.

The NO_2 monitor was calibrated by the California Air Resources Laboratory at El Monte and the Panalyzer was calibrated against a standard available at the Statewide Air Pollution Research Center, Riverside (SAPRC). Ozone and total oxidant concentrations are expressed as parts per million by volume (ppm) and micrograms per cubic meter ($\mu g/m^3$). The conversion is: 1 ppm = 1960 $\mu g/m^3$. Correspondence between ozone and total oxidant was compared at Sky Forest. PAN and NO_2 are expressed as ppm only.

Location of Monitoring Stations--

The biggest constraint in locating the monitoring stations was to find a source of electricity near the 18 permanent vegetation plots. The distribution of stations maintained from May through October (triangles, Fig. 1) conforms to the general downwind air flow from the urban basin, so that the gradient of oxidant concentration can be measured. Other locations where total oxidant (Mast) was measured for periods shorter than the May-October season include: UCC, CA, and HB (Fig. 1).

Appendix J lists the inventory of air monitoring data.

Classification of Meteorological Patterns in Relation to Pollutant Concentrations--

The ozone data for this study were analysed using the time-averaging method recommended by Larsen (1976). Daily average concentrations were used. The 361 sample days from the May-October periods of 1974 and 1975 were classified using the predictors and discriminant analysis method described by McCutchan and Schroeder (1973).

Surface windflow model design--To integrate the complexities of terrain effects on surface flow, a mathematical wind model was formulated by the Fire Meteorology Project (Ryan, 1974). The need for such a model was intensified by the lack of meteorological observations in mountainous areas. Thus, the model was designed to predict winds at remote locations if only sky condition, 850-mb data, and terrain height were available for input. If other data are available, the model is designed to incorporate them.

The model design is based on the premise that mountain winds are a result of the vectorial sum of component winds generated by several different mechanisms and factors. These factors included valley-mountain wind, slope wind, sea breeze, larger scale winds induced by pressure gradient and the sheltering and diverting effect of the terrain.

Results and Discussion

Within Season Meteorological Patterns and Ozone Dose--

Details describing the five meteorological patterns--An overview of the 1974, 1975 summer seasons (Fig. 11) shows two common characteristics relating to the distribution of the five classes of meteorological patterns. First, both seasons began and ended with a high marine air throughout the day. On such days, fog limited visibility to less than 20 m along mountain ridges between 1600 and 2100 m elevation msl. The temperature maximum on such days averaged 16 C and, there was considerable moisture condensation on conifer tree foliage. Second, there was a higher frequency of class 1 days from mid-September to late October. Class 1 days are typified by the presence of hot, dry, continental air throughout the day. The sky is usually cloudless and the strong Santa Ana winds often persist throughout the day. The daily temperature maximum averages 26 C. Class 2, 3, and 4 days dominate the period from early June through mid-September. The specific differences of these types of summarized in Table 5. Average daily temperature maxima for these days are 29, 26, and 22 C, respectively. These days differ mainly in the degree to which the moist marine air is modified as it flows inland and up the mountain slopes.

The most frequent wind direction (mode) and accompanying wind speed for each class of day is shown in Table 6. Camp Paivika and Barton Flats are better sited stations than Sky Forest for wind measurements. Winds during these 5 day classes have many common features; the only distinct type is class I.

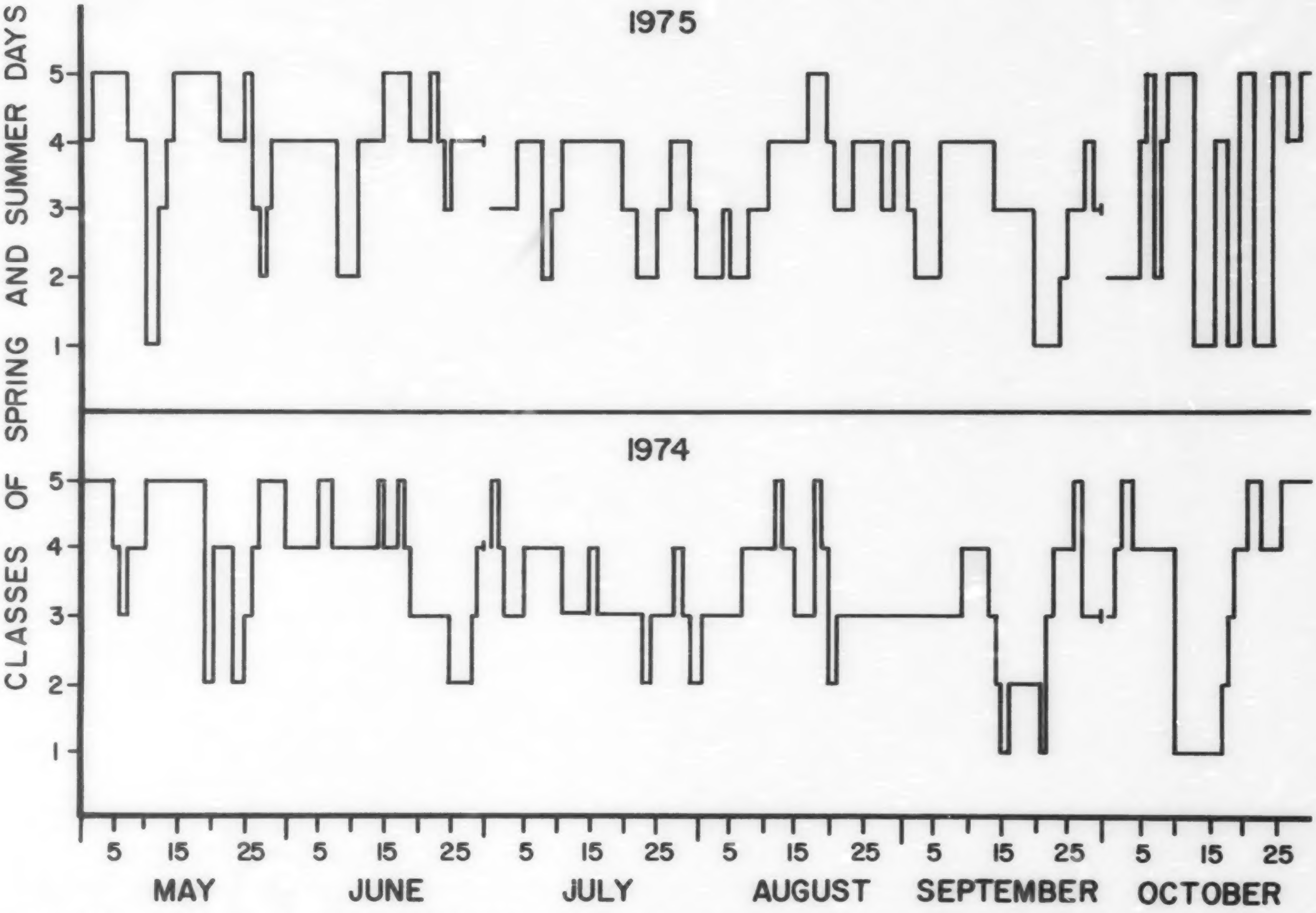


Figure 11. Sequences of five distinct meteorological patterns or day classes in the San Bernardino Mountains, 1974-1975.

TABLE 6. THE MOST FREQUENT (MODE) WIND DIRECTION (WD) AND ASSOCIATED AVERAGING WIND SPEEDS (WS) AT SELECTED HOURS DURING FIVE METEOROLOGICAL PATTERNS.

		10:00		12:00		14:00		16:00		18:00	
Station	Day type	Mode WD	Mean WS	Mode WD	Mean WS	Mode WD	Mean WS	Mode WD	Mean WS	Mode WD	Mean WS
Barton Flats	I	12[*]	5[+]	12	8	16	11	2	9	7	8
	II	12	8	12	10	12	11	11	7	7	5
	III	12	9	12	11	11	11	12	9	12	4
	IV	12	8	12	11	12	11	11	9	11	6
	V	14	10	12	11	14	9	12	7	13	17
Camp Paivika	I	16	20	16	25	16	25	16	28	16	25
	II	7	20	7	19	7	21	8	20	7	13
	III	7	19	7	24	7	26	8	18	7	18
	IV	7	21	7	23	8	25	7	25	8	19
	V	7	22	7	27	7	30	8	29	7	23
Sky Forest	I	15	8	8	9	9	5	16	5	1	6
	II	9	9	9	10	9	9	9	10	8	4
	III	9	9	9	11	9	11	9	10	8	5
	IV	9	10	9	12	9	13	9	12	9	8
	V	9	10	9	12	9	12	9	12	8	9

[*] Wind direction is expressed in terms of 16 compass points, e.g. 12 = west.

[+] Wind speeds are averages for "mode number" days only.

Cumulative ozone doses--At the Sky Forest monitoring station (1715 m, msl), the end-of-season dose in 1974 was more severe than that in 1975 (Fig. 12). The bars show biweekly dose increments and also demonstrate that the diminished dose of 1975 was fairly evenly distributed through all of the biweekly intervals. Further evidence suggests that a substantial difference in the frequency of the class 3 and 4 days throughout these seasons can be postulated as the cause of the difference in cumulative seasonal dose. The relationship between day class and concentration (daily average) equaled or exceeded 50% of the time (geometric mean) at Sky Forest is indicated in Table 7. The geometric means for classes 1-5 were 0.03, 0.09, 0.10, 0.09 and 0.06 ppm ozone, respectively, for the 361 days sampled at Sky Forest in 1974 and 1975.

Sequence of meteorological patterns and associated doses--A second way to compare the effect of day-classes on ozone concentrations is to consider the influence of all possible sequences of day-class changes, 25 combinations in all. In Table 8, 13 of the possible 25 are included; the other 12 which occurred less than 1% of the time for the 361 sample days were omitted from Table 8. Altogether, the 12 combinations omitted accounted for only 6.8% of the total. The last column of Table 8 is the cumulative ozone dose for the 24 hr of the second day of the combination. The "3-3" combination, which was more prevalent in 1974 than in 1975, resulted in one of the highest doses (2.09 ppm-hr). It appears that the "4-4" and "3-3" combinations were key ones which regulated the cumulative seasonal doses in 1974 and 1975 (Figs. 11, and 12). There were 22 more "4-4" classes in 1975 than in 1974; but in 1974, there were 36 more "3-3" classes than in 1975, resulting in higher 1974 cumulative dose.

Oxidant concentration trends during consecutive days of each pattern--A third way to evaluate the effect of transitional combinations is to examine the number of consecutive days a single-day-class persisted and to observe the trend of the 24-hr ozone average for each successive day of the sequence (Fig. 13). Again, the class 3 and 4 days are prominent because they did persist up to 10 days in each case, and the average daily ozone concentration remained around 0.10 ppm during these sequences. Class 5 days persisted up to 9 days, but there was a certain decline in the ozone concentration of each successive day. Class 1 and 2 days persisted up to 6 and 5 days, respectively, and both showed a downtrend in ozone concentrations; there is some suggestion that the second and third days in a class 2 sequence may result in slightly higher daily ozone averages.

Pollutant Transport--

Surface wind flow and oxidant concentrations during May through October at three stations--The averages of wind direction (expressed as one of 16 compass points) and wind speed (km/hr) for selected daylight hours is shown in Tables 9a, 9b, and 9c. In these tables, all meteorological patterns are combined. Before 1000 hr and after 1800 hr, oxidant concentrations were always lower; thus, this 8 hr period represents the worst case conditions. At all stations and in all months, the maximum hourly average oxidant concentration occurred at around 1600 hr. This was preceded at 1400 hr or was coincident with the highest average wind speed for the day. At Camp Paivika the source of flow was S or SSE;

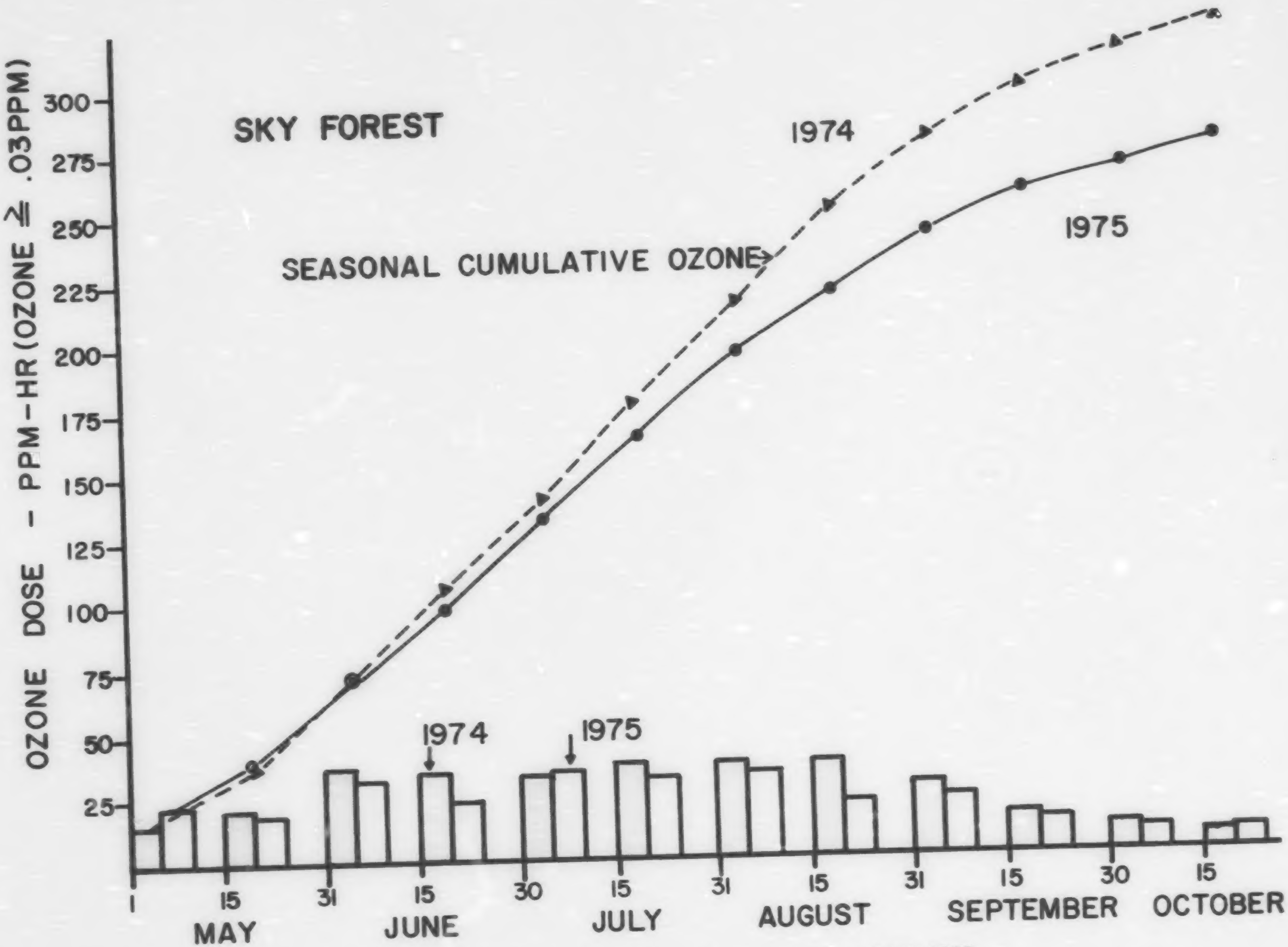


Figure 12. Biweekly and seasonal cumulative ozone dose at Sky Forest, 1974-1975.

Table 7. PERCENT OF TIME DURING FIVE CLASSES OF METEOROLOGICAL PATTERNS THAT SPECIFIED OZONE CONCENTRATIONS WERE EQUALITED OR EXCEEDED AT THREE SAN BERNARDINO MOUNTAIN MONITORING STATIONS FROM MAY THROUGH OCTOBER, 1975-1975.

STATION	ELEVATION	DISTANCE EAST OF SKY FOREST	PERCENT DATA	DAY CLASS	NUMBER OF DAYS	PERCENT OF TIME CONCENTRATION IS = OR ≥											STANDARD GEOMETRIC DEVIATION
						1	10	20	30	40	50	60	70	80	90	99	
SKY FOREST	1715 m (5640 ft)	0	99.5	1	22	0.11	0.06	0.06	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.01	1.7
				2	43	0.17	0.14	0.12	0.11	0.10	0.09	0.09	0.07	0.07	0.05	0.03	1.4
				3	104	0.17	0.14	0.13	0.12	0.11	0.10	0.10	0.09	0.08	0.07	0.04	1.3
				4	124	0.14	0.13	0.12	0.11	0.10	0.09	0.09	0.07	0.06	0.05	0.02	1.4
				5	69	0.14	0.10	0.09	0.08	0.06	0.06	0.05	0.04	0.04	0.03	0.02	1.5
SNOW VALLEY	2061 m (6780 ft)	12 km (8 mi)	84.2	1	17	0.06	0.05	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	1.3
				2	32	0.10	0.08	0.07	0.06	0.06	0.06	0.05	0.05	0.04	0.04	0.03	1.3
				3	97	0.10	0.08	0.07	0.07	0.07	0.06	0.06	0.05	0.05	0.04	0.03	1.2
				4	116	0.10	0.08	0.07	0.07	0.07	0.06	0.05	0.05	0.04	0.04	0.03	1.2
				5	48	0.09	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.04	0.04	0.03	1.1
BARTON FLATS	1946 m (6400 ft)	24 km (16 mi)	92.3	1	15	0.09	0.08	0.05	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.03	1.3
				2	43	0.19	0.12	0.08	0.07	0.06	0.05	0.05	0.05	0.04	0.04	0.03	1.7
				3	104	0.12	0.10	0.08	0.08	0.07	0.07	0.06	0.06	0.05	0.04	0.02	1.2
				4	123	0.13	0.10	0.09	0.09	0.08	0.07	0.07	0.06	0.05	0.04	0.02	1.3
				5	55	0.11	0.08	0.07	0.07	0.06	0.05	0.05	0.05	0.03	0.03	0.02	1.3

TABLE 8. FREQUENCY OF THE MOST COMMON TRANSITIONAL COMBINATIONS OF DAY CLASSES OR METEOROLOGICAL PATTERNS AND RESULTANT OZONE DOSE.*

Transitional combinations		1974	1975	Total	Percent of total	Dose, second day of combination ppm-hrs $\geq$ 0.03 ppm
4	4	32	54	84	23.2	1.76
3	3	53	17	70	19.4	2.09
5	5	22	22	44	12.2	0.78
2	2	8	16	24	6.6	1.88
3	4	11	8	19	5.2	1.90
4	5	9	9	18	5.0	1.50
4	3	8	8	16	4.4	1.77
5	4	9	7	16	4.4	1.42
1	1	6	9	15	4.2	0.38
2	3	6	6	12	3.3	2.10
3	2	4	6	10	2.8	1.80
2	4	1	4	5	1.4	1.31
4	2	2	2	4	1.1	2.20

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*The 12 remaining combinations of the possible 25 were excluded because individually they occurred less than one percent of the time.

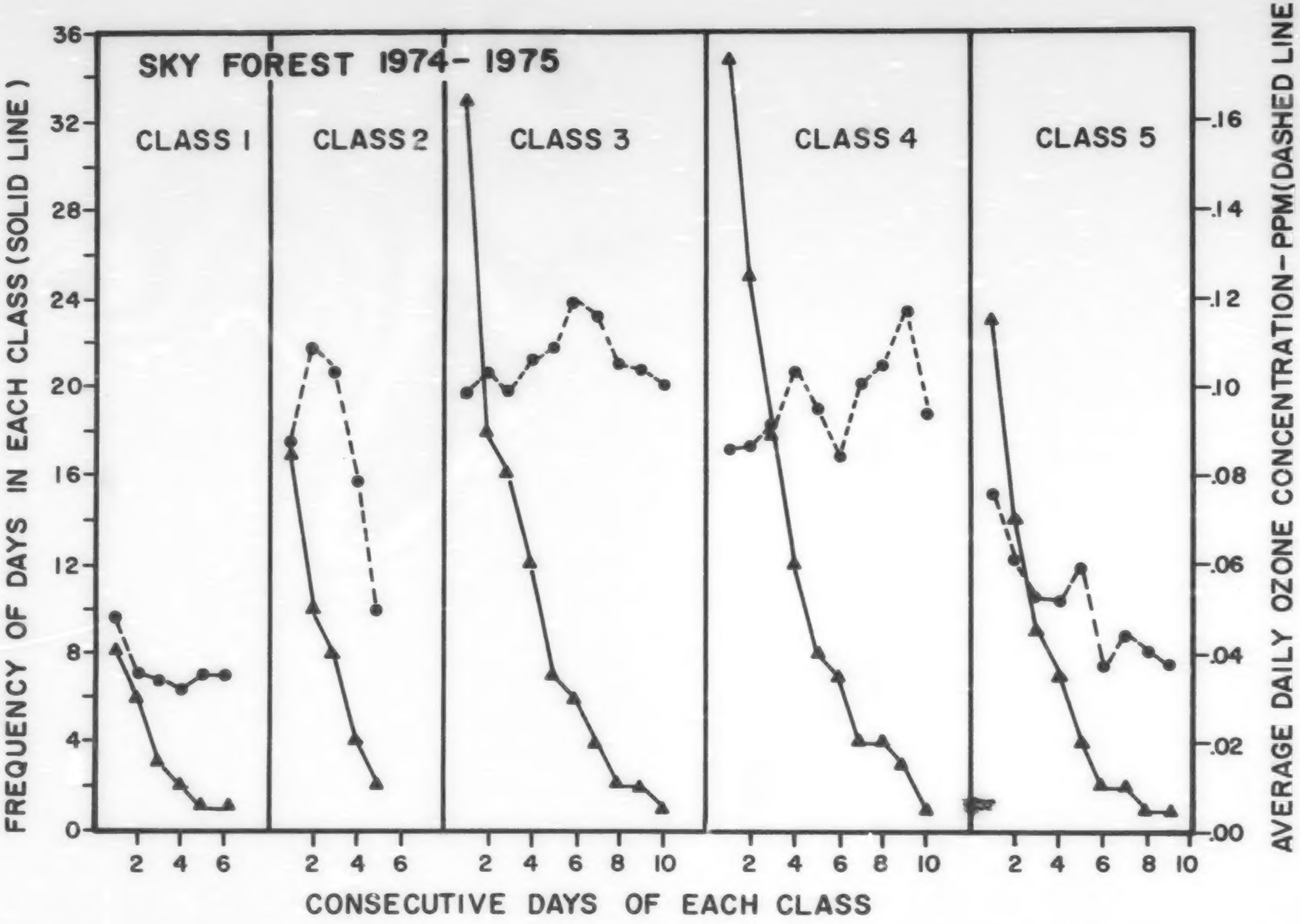

Figure 13. The frequencies of occurrence of each meteorological pattern on consecutive days, and the daily average ozone concentrations on consecutive days of each pattern at Sky Forest, 1974-1975.

TABLE 9a. COMPARISONS OF HOURLY AVERAGES FOR WIND DIRECTION (WD), WIND SPEED (WS) AND OZONE (DASIBI) AT BARTON FLATS DURING MAY THROUGH OCTOBER, 1975.

	10:00			12:00			14:00			16:00			18:00		
Month	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone
May	9	10	7	13	10	8	13	11	11	13	11	14	13	5	12
June	12	8	8	12	11	11	12	12	13	12	10	17	11	5	14
July	13	8	5	11	10	9	12	11	12	12	9	15	12	4	16
August	13	8	6	12	12	8	12	13	12	12	9	15	12	3	15
Sept	10	9	4	11	10	6	10	9	7	9	8	10	8	5	6
Oct	12	8	-*	11	9	-	12	8	-	12	8	-	8	7	-

TABLE 9b. COMPARISONS OF HOURLY AVERAGES FOR WIND DIRECTION (WD), WIND SPEED (WS), AND OZONE (DASIBI) AT CAMP PAIVIKA DURING MAY THROUGH OCTOBER, 1975.

	10:00			12:00			14:00			16:00			18:00		
Month	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone
May	7	13	-*	8	15	-	7	21	-	10	21	-	7	16	-
June	7	19	9	8	21	13	8	24	17	8	23	17	8	20	17
July	7	18	13	7	23	18	8	25	21	8	24	23	8	20	19
August	7	19	11	7	25	11	7	29	17	7	26	18	7	19	17
Sept	9	16	8	7	18	10	8	22	13	8	17	15	7	15	10
Oct	8	21	5	9	21	6	9	22	7	7	21	9	8	18	7

TABLE 9c. COMPARISONS OF HOURLY AVERAGES FOR WIND DIRECTION (WD), WIND SPEED (WS) AND OZONE (DASIBI) AT SKY FOREST DURING MAY THROUGH OCTOBER, 1975.

	10:00			12:00			14:00			16:00			18:00		
Month	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone	WD	WS	Ozone
May	10	9	8	10	10	10	10	11	15	10	11	16	9	6	17
June	9	9	9	9	11	14	9	12	18	9	12	19	9	7	13
July	9	9	10	9	10	16	9	12	20	9	12	22	9	7	16
August	9	10	8	9	12	12	9	13	16	9	12	20	8	7	16
Sept	10	7	7	9	10	9	9	9	12	10	8	15	8	4	7
Oct	9	9	5	10	9	6	9	9	7	10	9	7	9	6	5

* = Insufficient Data for Comparison

Sky Forest was SSW or SWS; and Barton Flats was generally W. The effect of terrain on flow is evident from the general configuration of ridges and drainages shown in Figure 10, and as described below.

Pollutant penetration during days representing different meteorological classes--Continuous ozone measurements for 1974 and 1975 from two additional mountain stations (Snow Valley and Barton Flats) were compared with those of Sky Forest (Fig. 10). Snow Valley is 12 km east and 346 m higher than Sky Forest; the terrain resembles a shallow basin tilted slightly to the west-southwest. The Sky Forest station is located on a south-facing slope just below the crest of a smooth ridge top. Barton Flats is 24 km east and 231 m higher than Sky Forest; it is situated on a north-facing slope at 1946 m overlooking a prominent canyon which opens to the west. The canyon bottom is about 230 m below and directly north. The question of interest is whether certain meteorological patterns aid deeper penetration of polluted air farther eastward and up to higher elevations in the mountains.

A comparison of concentrations in the 50% column for the three stations (i.e., the geometric means; see Table 7) showed that classes 2, 3, and 4 were equally effective at Snow Valley and that class 3 and 4 days were most conducive to pollutant transport to Barton Flats. Station comparisons in the 10% column showed that pollutant transport was most effective during class 2 days at Barton Flats. Since class 2 days are the hottest, it is possible that the up-canyon flow was much stronger on these days; thus, higher concentrations of ozone penetrated farther eastward. The high concentrations on class 4 days (10% column) may not be related to the late afternoon surge of air flow but rather to the fact that the inversion base is relatively high in the morning (approximately 1067 m) and oxidant concentrations approaching 0.20 ppm can be detected by 0900 PST in lamina above the inversion base (Edinger et al., 1974). The westerly wind component soon delivers this polluted air to the forested mountains because the elevation differential has been considerably diminished by this relatively high inversion base.

Modeling of surface wind flow and pollutant penetration on a class 4 day--The detailed terrain effects on wind flow (Fig. 14) were computed for a limited area (see Box, Fig. 15) by Ryan's model for 1300 PST on August 31, 1974. Detailed terrain effects on wind flow for the entire area (Fig. 15) are not modeled because of lack of both terrain and wind data at the present time.

The synoptic conditions on August 31 resemble a class 4 day with generally high air pollution potential (McCutchan and Schroeder, 1973). A surface thermal trough was over the desert, and a weak 500 mb trough was just off the coast of southern California. Flow aloft was southwesterly, and the sea breeze was strong from the southwest. The combined effect produced a prevailing surface wind from the southwest with speeds near 6.7 m/sec (15 mph).

Sheltering of the fairly strong southwest flow resulting from the

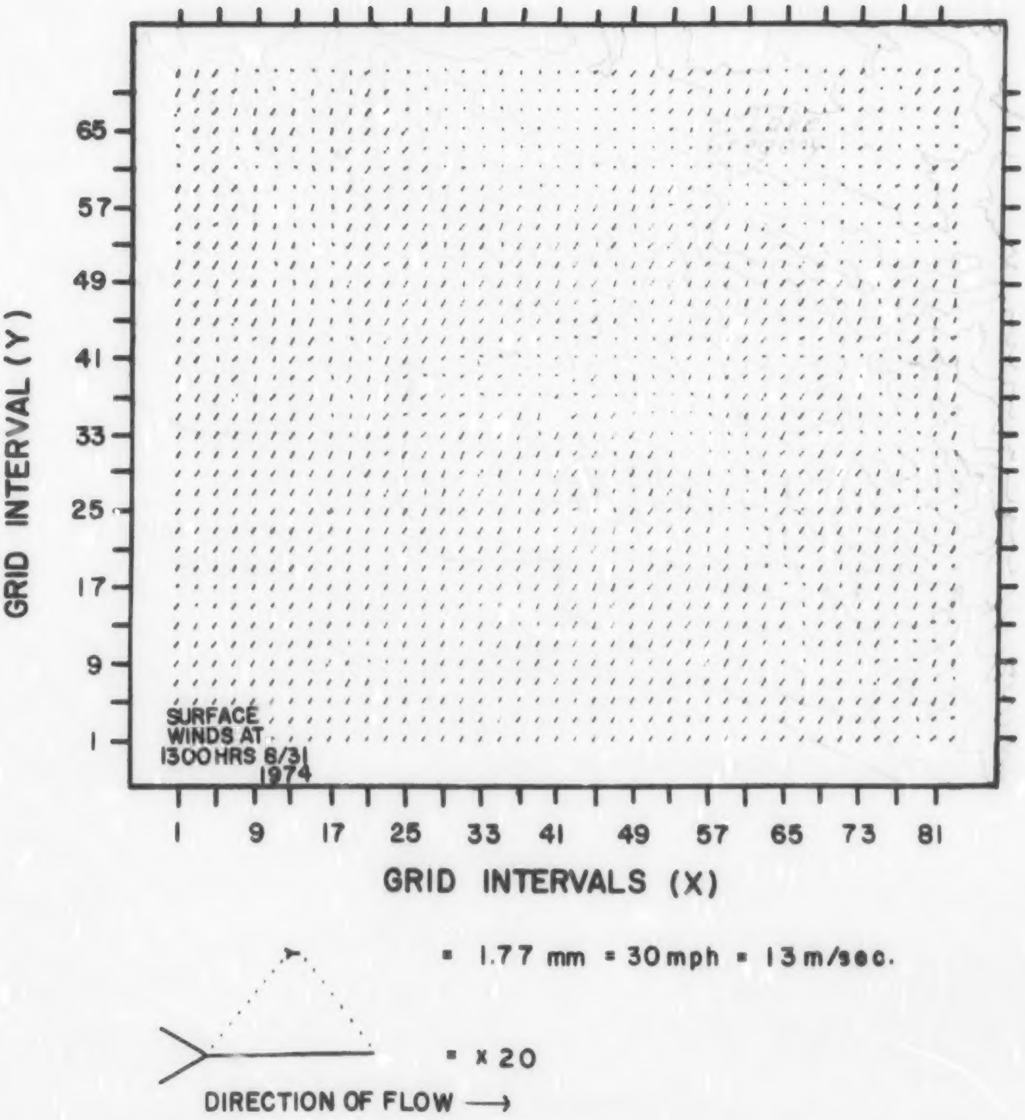

Figure 14. Surface wind fields generated from a computer model for 1300 hr PST, August 31, 1974, for a limited portion of the study area (see caption in next figure).

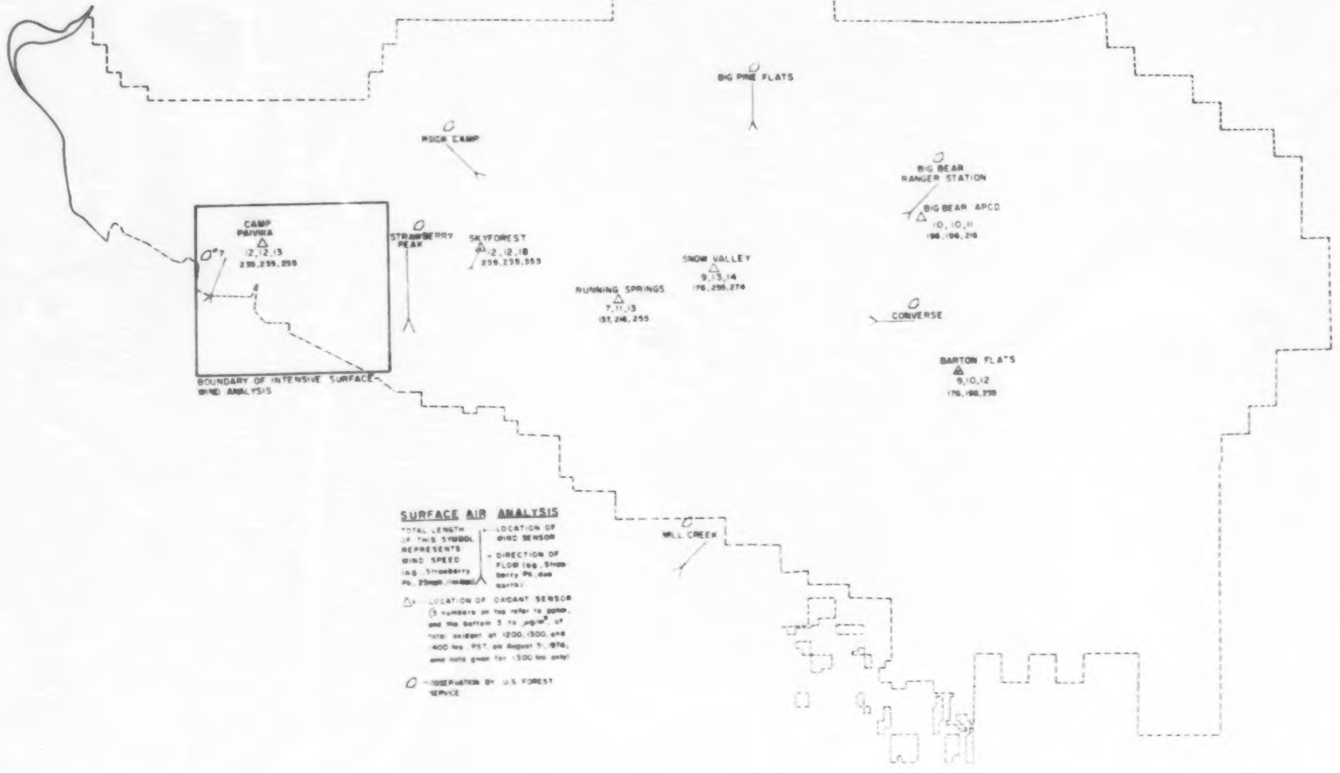
BIG PINE FLATS
ROCK CAMP
BIG BEAR
RANGER STATION
BIG BEAR APCD
10, 10, 11
196, 196, 216
CAMP
PAIVIKA
12, 12, 13
235, 235, 255
STRAWBERRY
PEAK
SKYFOREST
12, 12, 18
235, 235, 353
SNOW VALLEY
9, 13, 14
176, 255, 274
RUNNING SPRINGS
7, 11, 13
137, 216, 255
CONVERSE
BARTON FLATS
9, 10, 12
176, 196, 235
BOUNDARY OF INTENSIVE SURFACE WIND ANALYSIS
MILL CREEK
SURFACE AIR ANALYSIS
TOTAL LENGTH OF THIS SYMBOL REPRESENTS WIND SPEED
LOCATION OF WIND SENSOR
DIRECTION OF FLOW
LOCATION OF OXIDANT SENSOR
OBSERVATION BY U.S. FOREST SERVICE

Figure 15. Wind direction and speed at selected surface stations at 1300 hr PST, August 31, 1974, compared with the concentration of total oxidants at 1200, 1300, and 1400 hours PST.

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effects of terrain can be seen in several areas such as around grid point X = 31, T = 61 and around X = 46, Y = 36. In these areas, the strong flow is blocked by higher terrain up-wind. In contrast to these sheltered areas, channels through which strong winds are allowed to flow are evident, such as near grid point X = 16, Y = 66. Examples of directional change caused by terrain effects are also displayed, e.g., at gridpoint X = 21, Y = 61. Changes in wind direction are the result of three different terrain effects: mechanical diversion, wind component produced by differential heating on slopes, and wind component produced by differential heating in valleys.

Observed prevailing surface winds were south-to-southwest over the entire area (Fig. 15). Variation from the prevailing direction owing to terrain influence is evident at Converse. The east-west orientation of Santa Ana Canyon is responsible for the west wind at Converse.

The hourly average of total oxidant concentrations at 1200, 1300, and 1400 hr (the hours before, during, and after wind observations) are indicated in Figure 15, where monitoring stations were present. For example, concentrations at Sky Forest were 235, 235, 353 $\mu g/m^3$ for the three consecutive hours. The expected increases of concentrations to a daily maximum sometime after 1400 (Tables 9a, 9b, and 9c) are evident at all six monitoring stations. If detailed wind fields can be obtained with the model for the whole mountain area, it will be possible to evaluate the relationships of flow patterns and pollutant dispersion in relation to forest vegetation injury.

Definition of the Oxidant Dose Gradient in the San Bernardino Mountains--

Characterization of the west-to-east gradient of seasonal oxidant doses--Seven ground stations were maintained from June through October, 1974, along a west-to-east transect. These stations can be located by intersection on the scales superimposed above the topographic projection of the San Bernardino Mountains (Fig. 16). The cumulative monthly doses presented in Figure   do not include data from every hour possible during each month because of intermittent instrument failure. On the average, at least 90% of the data are available. Since 1974 was one of the most severe air pollution years on record (Fig.   ), these data probably represent an overestimate of the average doses along this gradient in previous years.

As we have suggested from data in Figures 14, and 15, terrain is the likely cause of the rapid decline in dose between Sky Forest (SF) and Snow Valley (SV) because the elevation gradually increases from 1661 m (5,450 ft) to 2052 m (6,750 ft). The slight dose increase at Big Bear Dam (BBD) occurs because the monitoring station is in a notch which channels air flow at the top of a major canyon leading up from the basin. The terrain along the interval between BBD and the Big Bear Air Pollution Control District (BBAPCD) is primarily lake surface. Barton Flats (BF) monitoring station is located on the forested north slope of the Santa Ana River drainage and is exposed to the unimpeded afternoon up-canyon flow of polluted air. The information in Figure 16 does not adequately represent the complete eastward extent of pollutant transport in the mixed conifer forest which is necessary to fully define the dose gradient. Also,

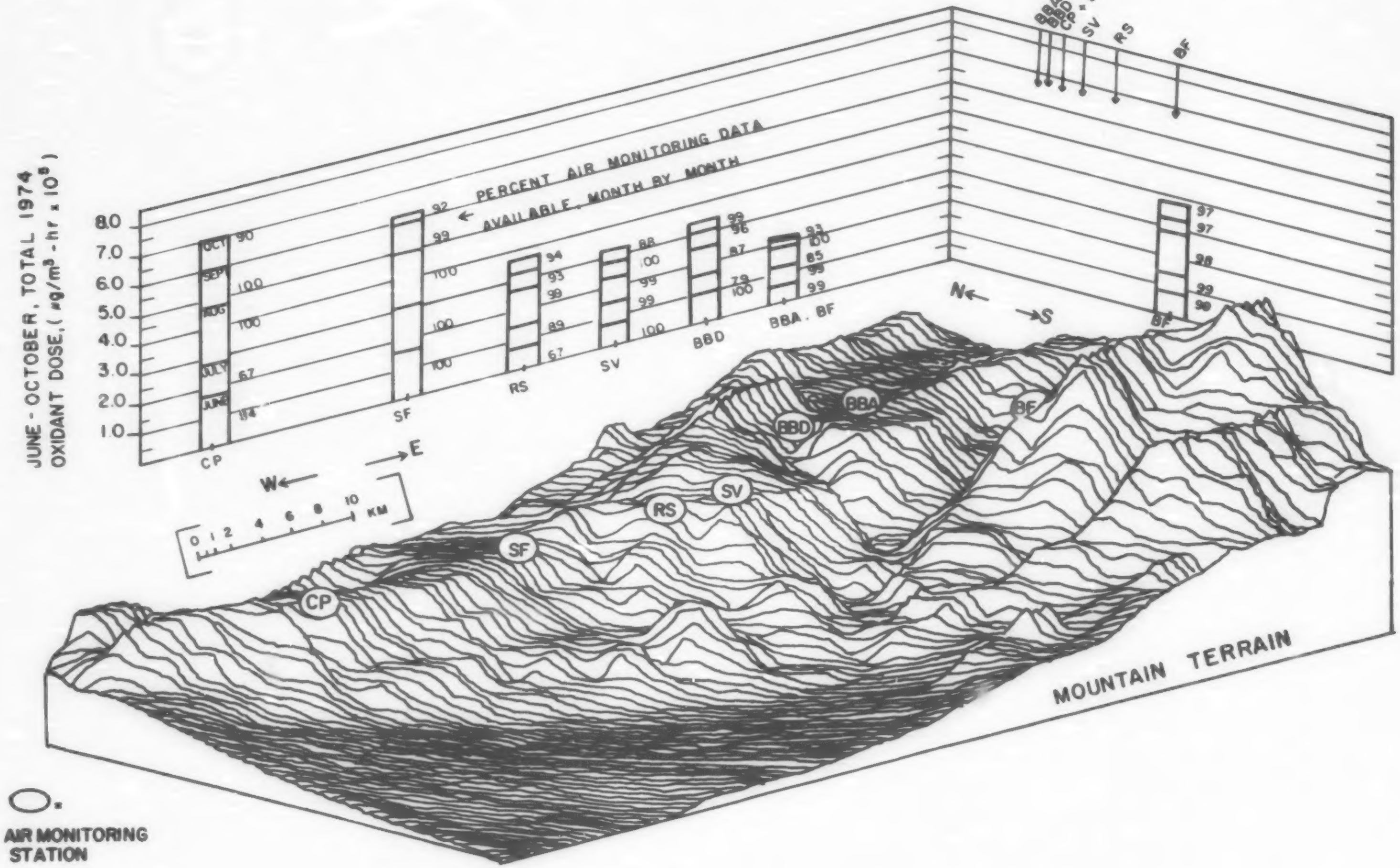


Figure 16. Topographic projection of the San Bernardino Mountains showing monthly summation, June through October 1974, of total oxidant dose at seven monitoring stations. The percent of total data recovered is indicated by month at each station. Locations were: Camp Paivika (CP), Sky Forest (SF) Running Springs (RS), Snow Valley (SV), Big Bear Dam (BBD) Big Bear Air Pollution Control District (BBAPCD) and Barton Flats (BF). (For absolute values, oxidant concentrations and doses might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et al., 1976)

the western part of the transect generally overlooks the basin, and additional data must be otained by placing stations in a south-to-north configuration.

In Figure 17, the total hours with oxidant concentration $\geq$ 157 $\mu g/m^3$, the Federal Standard, are separated into day and night-time hours for August, September, and October, 1974. It is readily apparent that the western, lower elevation monitoring stations receive more night-time hours when oxidant concentrations exceeded 157 $\mu g/m^3$, especially at Camp Paivika. The greater oxidant concentration at night may be associated with the nocturnal position of the inversion layer which acts as a reservoir for oxidant (Edinger, 1973). The west-to-east gradient of decreasing oxidant dose is plainly evident in this analysis, as well as in Figure 16.

The time averaging analysis (Larsen, 1973) was also used to compare these stations in 1974. The geometric means were as follows: CP = 0.075; SF = 0.068; RS = 0.049; SV = 0.045; BBD = 0.055; BBAPCD = 0.034; BF = 0.045. These numbers should be rounded off to two decimal places.

Comparative daily maximum hourly averages for ozone, total oxidant, PAN, and NO_2 at Sky Forest, August 1974--Daily concentrations of ozone and total oxidant for August 1974 closely mimic one another (Fig. 18). Except for one day (August 8) data from the DASIBI ultraviolet spectrophotometer, which measures ozone specifically, were always lower than the Mast KI instrument, which responds to other oxidants. It is important to observe that ozone is a good surrogate for total oxidant measurement; in addition, it is the most important pollutant causing injury to conifers. Because August is usually one of the more severe months for pollution, this record probably displays one of the highest frequencies of air pollution episodes to be expected in the mountain area, especially in 1974, (See Fig. 16). PAN concentrations were sufficient to cause injury to common herbaceous plants frequently used in laboratory studies, but PAN symptoms were not distinguished from ozone symptoms on nearby herb layer plant species. Nitrogen dioxide remained at low, probably nonphytotoxic, concentrations compared to the other oxidants.

Comparative hourly concentrations of total oxidant, NO_2 and PAN--A comparison of total oxidant at SF, BB, and BF, with winds at SF and Big Bear Ranger Station during two days in October, 1973 (Fig. 19), shows that total oxidants may peak out later at more distant stations (October 18) or nearly simultaneously (October 19). The stronger winds on the 19th may have caused the more uniform peaking time. At SF, PAN peaks later than total oxidant. Nitrogen dioxide has a very small peak around 0800 hr and a slightly larger one at from 2000 to 2100 hr PST.

Air Quality Standards and Historical Trends in Oxidant Concentrations and Seasonal Doses--

One acceptable way of identifying trends in air pollution doses is to compare the number of days or total hours each year when concentrations exceed some threshold higher than the Federal Standard (160 $\mu g/m^3$). At the selected threshold, human health and welfare is imperiled, especially because the daily peak oxidant concentration on these days can reach up to 1176 $\mu g/m^3$ (0.60 ppm). Local communities and both State and Federal agencies have

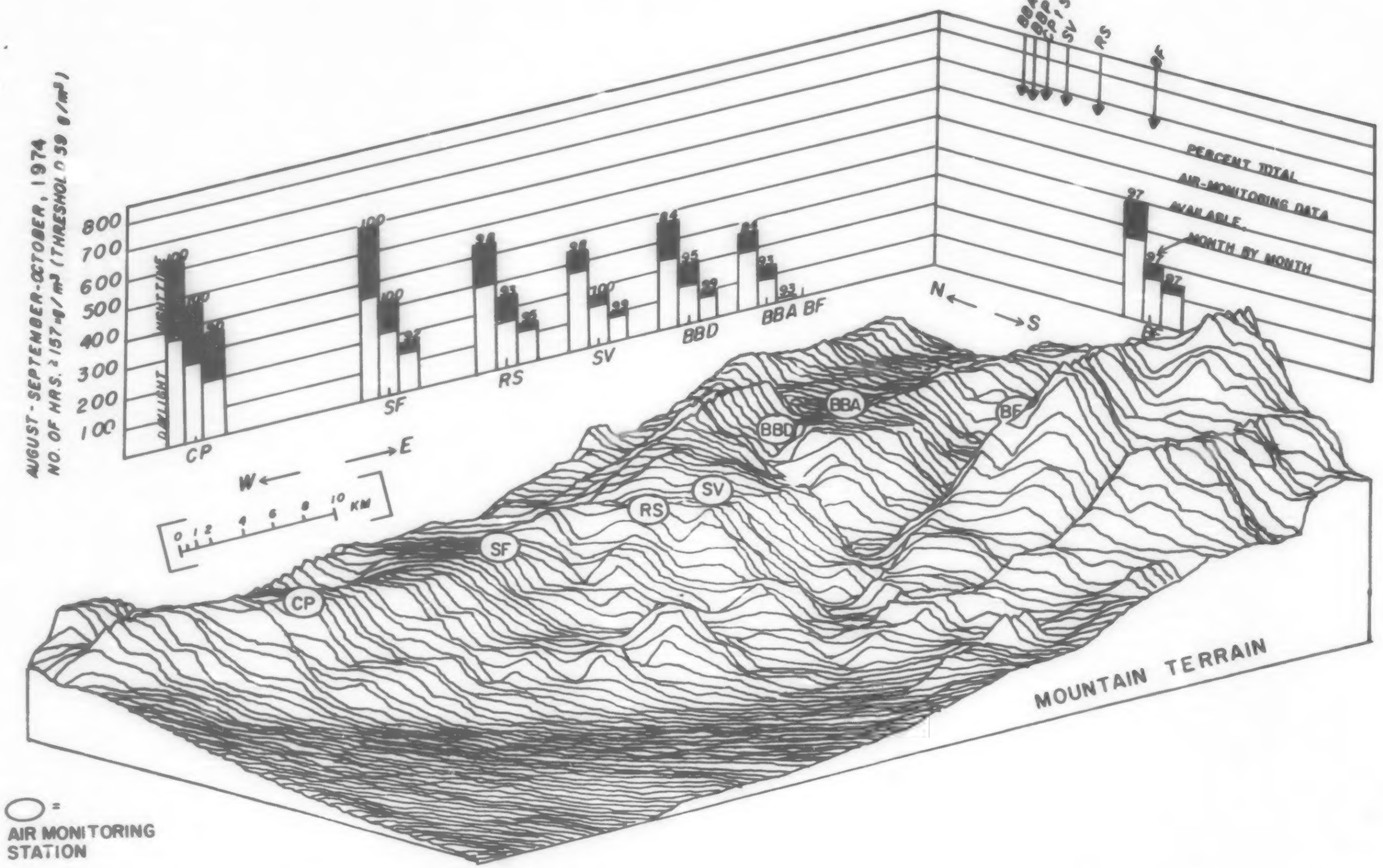


Figure 17. Topographic projection of the San Bernardino Mountains with a comparison of total daylight and night hours during August, September, and October 1974, when total oxidant concentrations were greater than, or equal to 157 $\mu g/m^3$ (0.08 ppm) at seven air monitoring stations. Hours less than 59 $\mu g/m^3$ were excluded as natural background. Station names are described in caption for the previous Figure; they can be located by intersection. (For absolute values, oxidant concentrations and doses might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et.al. 1976.)

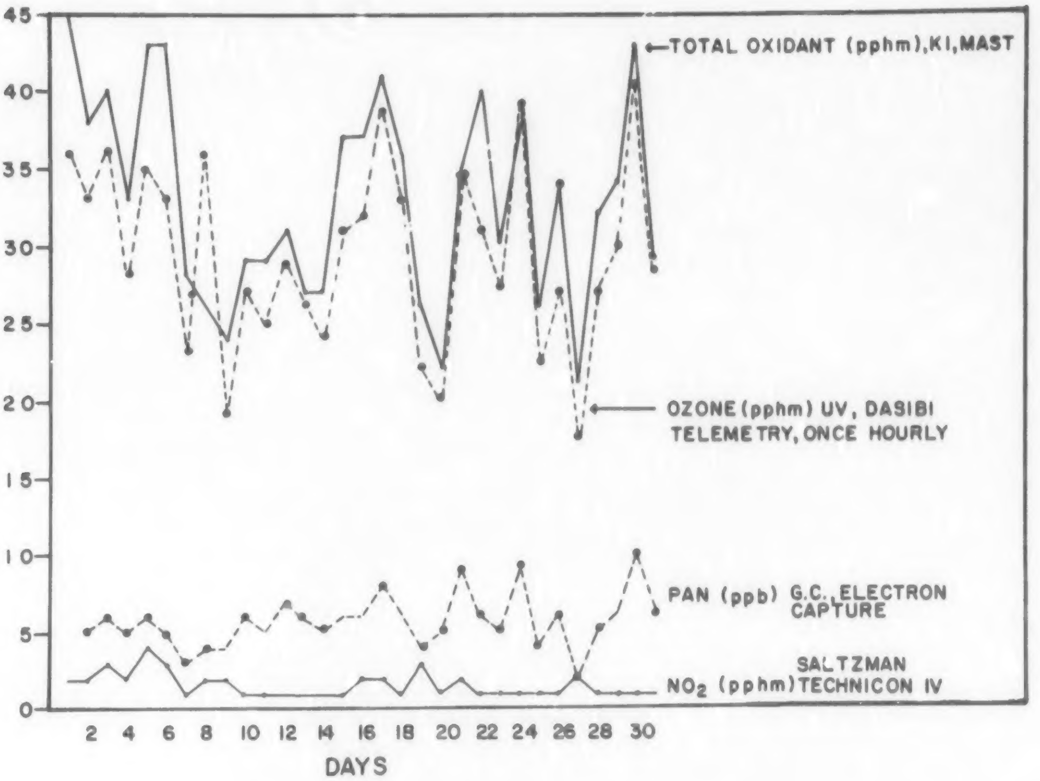


Figure 18. Comparative daily maximum hourly averages for ozone, total oxidant, PAN and NO_2 at Sky Forest, August 1974. (For absolute values, oxidant concentrations might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et al., 1976)

adopted different threshold values to signify adverse effects. The State of California employs several descriptive thresholds, one being 392 $\mu g/m^3$ (0.20 ppm), to identify the frequency of air pollution episodes or periods of sustained high concentrations of atmospheric pollutants.

Concentrations at San Bernardino and Rim Forest/Sky Forest--Data from the mountain station at RF/SF were compared with published data from the San Bernardino County APCD in terms of the number of hours during which total oxidant concentration exceeded 392 $\mu g/m^3$ (0.20 ppm) during July, August, and September from 1968 to 1974, when both stations operated. From 1963 to 1967, data are available only from the San Bernardino APCD station Air Resources Board (1973). A large part of the year-to-year differences at the same station and between stations can be attributed to differences in 1972, 1973, and 1974, at RF/SF (Fig. 20) are associated with 6, 16, and 46 days, respectively, when a persistent 500 mb high pressure system (class

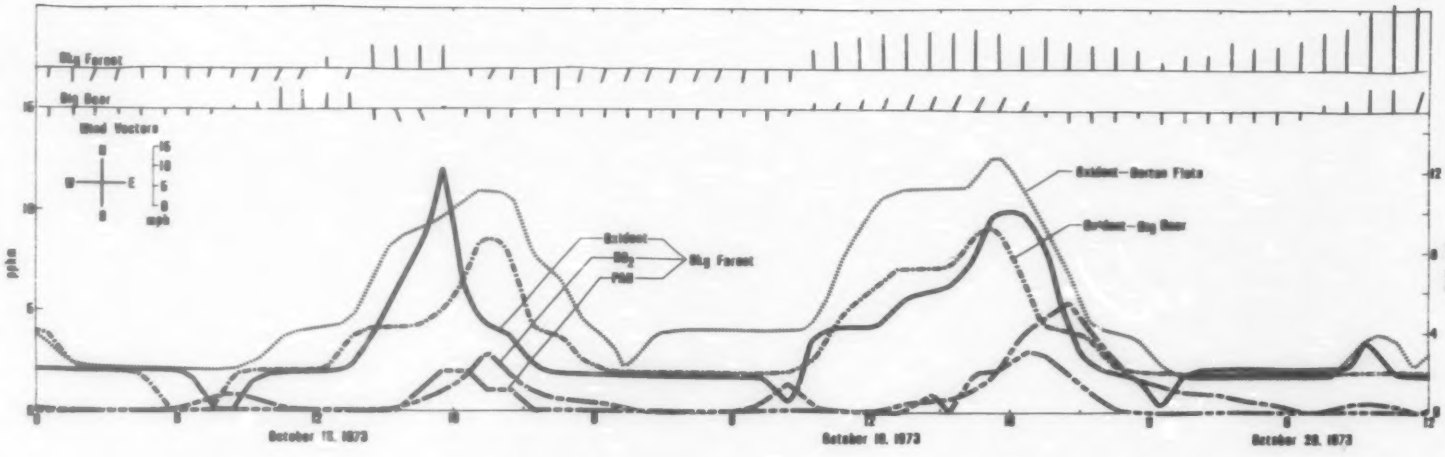


Figure 19. Comparative hourly concentrations of total oxidant, PAN, and NO_2 at Sky Forest, November 18, 19, 1973, and total oxidants at Big Bear Ranger Station and Barton Flats. (For absolute values, oxidant concentrations and doses might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et al., 1976)

3 and 4 type days, Table 5) occurred over the southwest, particularly over southern California. The difference between stations in the same year is probably influenced most by inversion height. Lower inversion heights would partially restrain transport upslope to shorter periods daily. Higher inversions mean longer periods of upslope flow and, in addition, allow a greater air volume below to dilute oxidants. The index for comparison chosen in Figure 20, i.e., hours with total oxidant concentration $\geq$ 392 $\mu g/m^3$, should be largely determined by inversion height. The three-year moving averages for each station tend to remove some of the variation due to higher frequency fluctuations. In terms of hours with total oxidant concentration ($\geq$ 392 $\mu g/m^3$), the moving average between 1970 and 1973 at SF/RF increased from 175 to 290 hr. This trend is the reverse of that in upwind, urban Los Angeles County, where increased emissions of NO (nitric oxide in fresh auto exhaust) tend to shift the chemical equilibrium to the left towards the ozone precursors in the chemical reaction which produces ozone.

Seasonal dose at Rim Forest/Sky Forest 1968-1976--A second method of documenting trends of oxidant levels during the 1968 to mid-1976 period at RF/SF expresses the accumulated dose ($\mu g/m^3$-hr) including concentrations for June through September (Fig. 21). This period represents the main part of the growing season; however, doses during the remaining months of the year are also being measured at this station. These doses exclude hourly concentrations $\leq$ the background concentration of 59 $\mu g/m^3$ (0.03 ppm), as reported by Gloria et al. (1974). The percent of valid data recovered is also indicated. The absence of some data, up to as much as 18% in 1970, but averaging 8.3% during the seven years, persents a margin of error that cannot presently be adjusted with any certainty. Future analysis of past meteorological data may permit some adjustments to be made. The percent of the total possible hours for which data could be obtained for each month during the June through September period is also indicated.

The most recent predictions suggest that oxidant doses will either increase annually or oscillate around the mean of present high levels in the foreseeable future at these distant locations unless dramatic improvements are made in control strategies (Corn et al., 1975; Blumenthal et al., 1974).

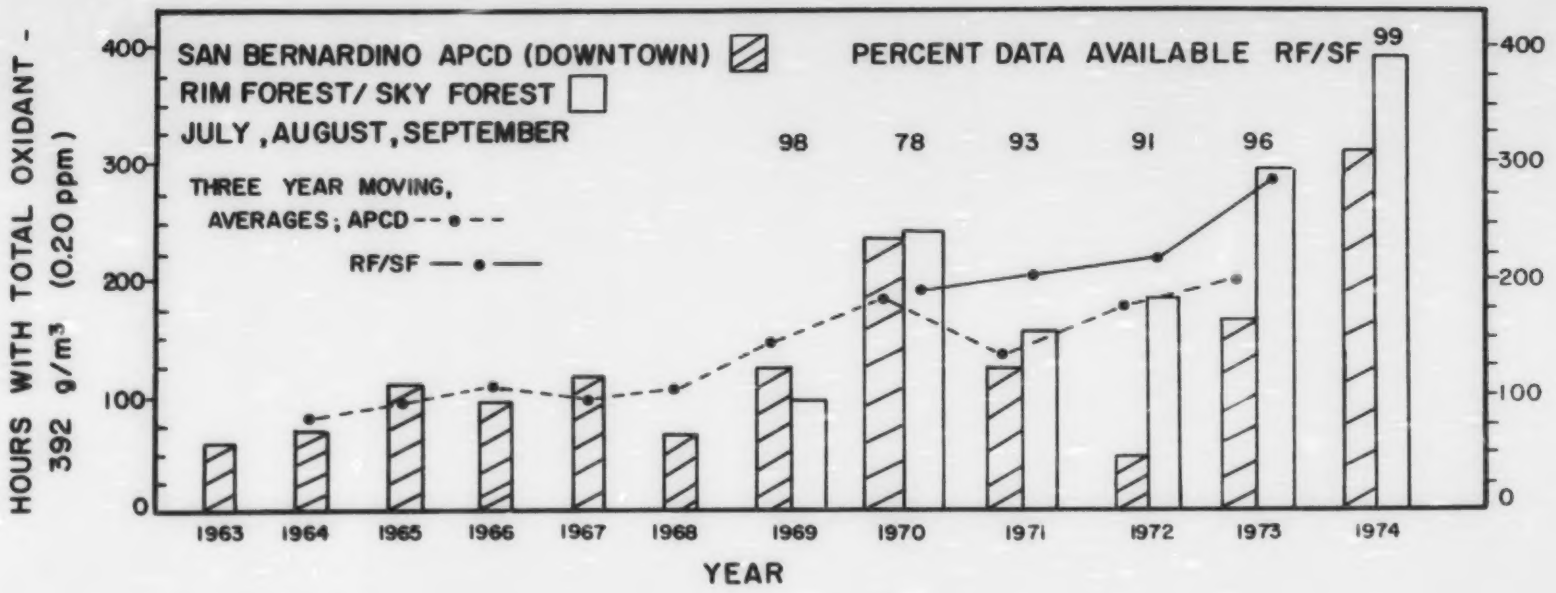


Figure 20. Number of hours of total oxidant, July through September, greater than or equal to 392 μg/m^3 (0.20 ppm) at the downtown San Bernardino County Air Pollution Control District Station, 1963-1974, and Rim Forest/Sky Forest, 1968-1974. (For absolute values, oxidant concentrations might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et al., 1976)

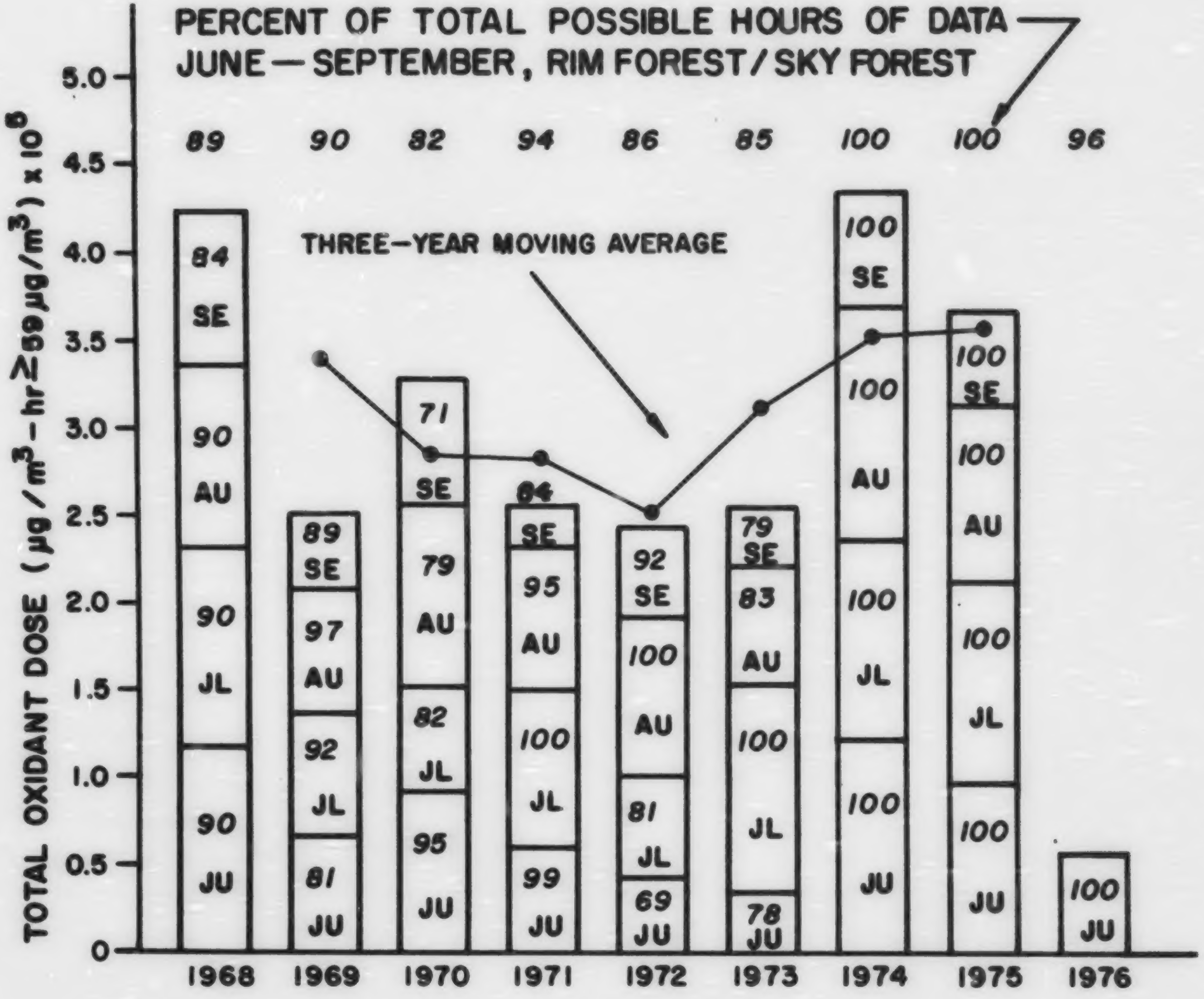


Figure 21. Monthly summation, June through September, 1968-75, of total oxidant at Rim Forest/Sky Forest

DEFINITION OF THE CONIFER FOREST ECOSYSTEM AS A GROUP OF COUPLED ECOLOGICAL MODELS

Introduction

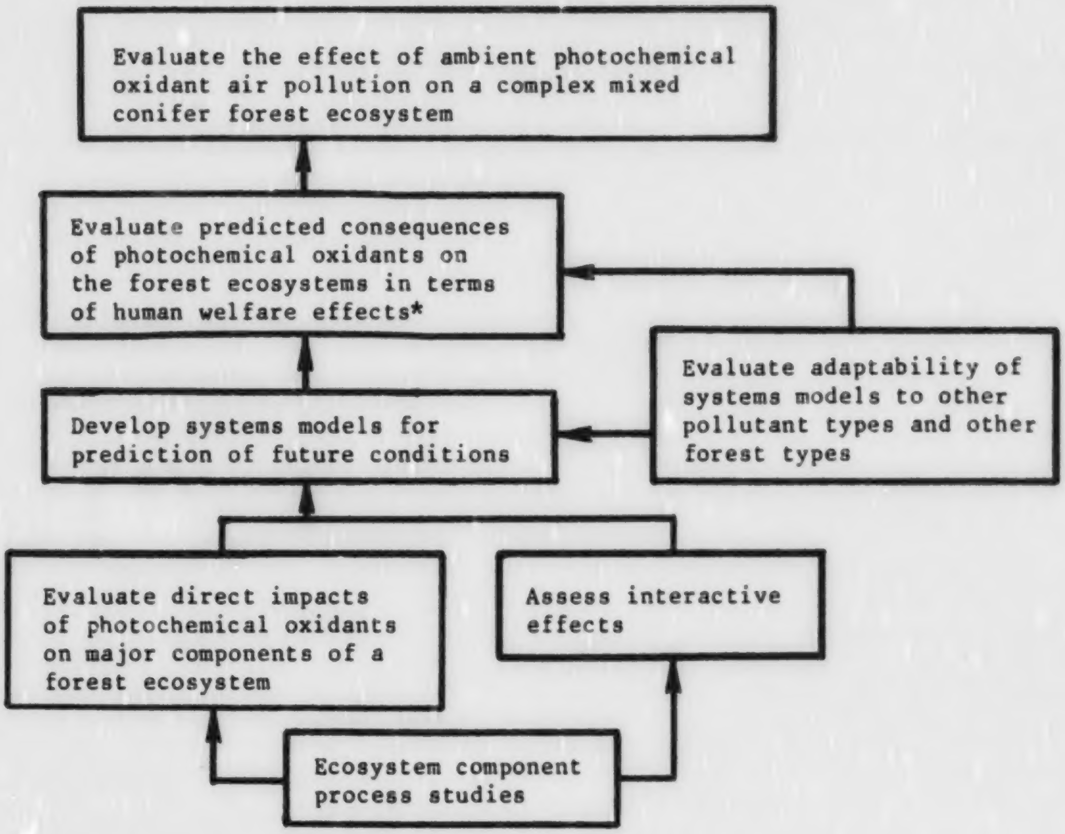
Background and Project Objectives--

Ecosystems are defined as units dependent upon (1) energy and moisture flowing through them and (2) minerals cycling within them; as a result (3) vegetation reproduces, grows, and dies, supporting (4) a diversity of animal life, some of which feeds on vegetation and some of which feeds on other animals. In ecosystems, (5) dead organic matter accumulates and (6) organisms decompose it to make minerals and space available for the next generation (Odum, 1971). At any given time, some organisms are more dominant than others in the ecosystem processes listed above as (3), (4), (5), and (6).

As time passes, these patterns of dominance go through a gradual change; in fact, the subject of ecological succession has received considerable study (Knapp, 1974). After a disturbance occurs in an ecosystem, time is set back, and the sequential patterns of dominance begin to occur again. In some cases, the nature of the disturbance may lead to a different sequential pattern of dominant plants and animals than the sequence prevailing before the disturbance. For example, an alteration of the natural accumulation, and/or decomposition, rates of dead organic matter may contribute to changes in the dominance patterns of vegetation and wildlife communities.

Several investigators are studying selected problems within this variety of processes in the laboratory and field as the first step in the hierarchy of project objectives (Fig. 22, bottom). These objectives center on applying methods of systems analysis and computer simulation modeling in the following areas: (1) developing models for forecasting ecological effects of photochemical air pollutants in southern California mixed conifer forest ecosystems; (2) evaluating the adaptability of these systems models to other pollutant and forest types; and (3) evaluating the predicted consequences of photochemical air pollutants in forest ecosystems on human welfare.

Studies of the processes carried out by components of ecosystems are necessary to determine and quantify direct oxidant effects as well as biological effects resulting from simultaneous occurrence of oxidants, drought, and insects and plant diseases. These analyses are necessary to assemble our understanding of various processes into a set of quantitative computer models. With such models, we plan to forecast the various possible alternative futures for the ecosystems in the San Bernardino National


Evaluate the effect of ambient photochemical oxidant air pollution on a complex mixed conifer forest ecosystem
Evaluate predicted consequences of photochemical oxidants on the forest ecosystems in terms of human welfare effects*
Evaluate adaptability of systems models to other pollutant types and other forest types
Develop systems models for prediction of future conditions
Evaluate direct impacts of photochemical oxidants on major components of a forest ecosystem
Assess interactive effects
Ecosystem component process studies

* ". . .includes, but is not limited to, effects on soils, water, crops, vegetation, man-made vaterials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

Source: Clean Air Act 1970, Section 302 (h).

Figure 22. Objectives for the study of effects of ambient oxidant pollutants on mixed conifer forest ecosystems.

Forest (SBNF) (Fig. 22, middle). Scientists do not expect to be able to make absolute predictions since too many qualifying conditions (e.g., the future use rate of the internal combustion engine, and its possible technological modifications; future weather conditions) cannot be predicted with certainty. Instead, we can forecast various possible alternative futures for the forest ecosystems by postulating sets of alternative, hypothetical qualifying conditions, and seeing how the set of computer simulation models responds to them.

For example, one set of possible future conditions might assume twice the 1974 annual oxidant dose with a three- or four-year wet-weather pattern of either 1 1/2 times or 1/2 the normal rainfall. We would then determine how the simulated forest system behaves on the computer. Of course, there is no guarantee that real forests will respond as computer models do, but given the options of using informal, intuitive guesswork on the part of individual specialists, or a synthesis of current scientific understanding of the processes which control whatever future forest conditions actually will occur, we prefer the latter.

Purposes for Building Computer Simulation Models of Ecosystem Level Response to Photochemical Air Pollutants--

Anticipating effects of possible futures--The types of ecosystem forecasts sought from using the computer models must evaluate likely consequences in terms of "human welfare effects" (Fig. 22, top). This is a vague expression from a systems analysis viewpoint, but it is defined in section 302(h) of the Clean Air Act, (Environmental Protection Agency, 1970):

> "All language referring to effects on welfare includes, but is not limited to, effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being."

We expect losses in the form of vegetative production decreases and (2) shifts in the balance of species abundance in forest ecosystems under oxidant air pollution stress. Nevertheless, one of the ultimate questions to "ask" forest ecosystem simulation models in order to evaluate consequences in terms of human welfare effects concerns ecosystem irreversibility. Is there some level of oxidant air pollution, in some time and space definition, at which irreversibility in forest stand succession patterns occurs? Further can oxidant air pollutants affect the resilience limits of terrestrial ecosystems? In particular, is the detection of such irreversibility possible within one human lifetime (e.g., between 1950, when photochemical air pollution is believed to have begun its chronic rise above natural background levels in the South Coast Air Basin, to 2000)?

In terms of the possible range of air quality conditions from now to the year 2000, one possibility could be a worsening of air quality in the SBNF by some factor 2, 3, or 4 times that at present. Under such an extreme, we might expect changes in the life forms of dominant vegetation to occur; as this was suggested by Woodwell's (1970) studies on the effects of gamma radiation. The other theoretical extreme, however, is that the present air pollution trend could be reduced by virtually 100% at some time within the next 25 years. The question of irreversibility asks (1) if this reduction occurs through political and technological procedures, and (2) if air pollution stress on forest ecosystems is removed (at inevitably high costs), might these ecosystems re-establish their pre-stress species composition after a period of readjustment? In other words, can oxidant air pollutants affect the renewability of mixed conifer forest ecosystems?

General assumptions being examined--The exploration and evaluation of two assumptions are the goals of this investigation. The first is to construct an ecosystem-level interpretation for stress induced by oxidant air pollution; the second is to apply analysis and forecasting methods.

Ecological systems under stress--Combinations of non-biological stresses lead to changes in the natural frequency of periodic biological stresses such as insect epidemics and disease epidemics. These non-biological stresses include increases in ground-level concentration of photochemical oxidants, changes in natural fire frequency distribution, changes in the frequency and intensity of timber removal, and various intensities of meteorological drought. As a result of these stresses, sequences of ecologically dominant vegetation undergo changes not likely to reverse naturally, even after the removal of any single non-biological stress.

Benefits of systems analysis approach--To conduct this study, we feel that a systems analysis and simulation modeling approach will provide participating scientists with a means of: (1) clarifying their concept definitions and explicitly exposing their assumptions which ordinarily would remain hidden; (2) clarifying relationships between system components; (3) collating a number of different scientists' data sets; (4) considering a larger set of interrelated ecological variables than any single investigator can observe in the field; and (5) comparing similarly structured systems, e.g. from different field plots, having different rates of change.

Simulation models can provide government agencies responsible for air quality and forest resources management with means of: (1) forecasting some likely responses of ecosystem properties (species composition, timber yield, community stability, or resilience) to possible air quality trends, forest resource harvesting methods, and other environmental stresses; (2) extending the range of relevance of a set of field investigations to other sites and other years (see Fig. 22, middle); (3) educating resource management personnel about possible consequences of alternative air quality and forest-management strategies through simulation-gaming. The usefulness of simulation-gaming for resource management personnel was treated by Holling and Chambers (1973) and Biswas (1975).

Literature Review

Evidence Supporting the Ecosystem Stress Interpretation--

Koenig and Tummala (1972) defined a concept involving three ecosystem states based on relative pollutant levels. The first of these is nonpollution. This state exists when pollutants do not affect the ecosystem state's capacity to meet the criteria of an "environmental quality region." We define an "environmental quality region" as a concept defined in terms of ecological state space, where "locations" define the region's capability for a set of resource uses by man. Woodwell (1975) refuted the existence of an ecosystem's assimilative capacity, even though Smith (1974) also advanced the concept.

A second state is reversible pollution. This occurs when the input rate of pollutant stress causes the ecosystem's temporary failure to meet the criteria which define an environmental quality region. However, when the stress is removed or neutralized by another counteractive stress, the ecosystem reverts to its original quality.

The third state is nonreversible pollution. In this state, pollutant stress causes the ecosystem's complete failure to meet the criteria which define an environmental quality region. In this case, the system remains at this inferior level even after subsequent reduction of pollutant stimuli.

Deficiencies in present terrestrial ecosystem stress-response theory--Woodwell (1970) defined the general sequence of the elimination of vegetative life forms from an eastern oak-pine forest. He utilized a spatial gradient of increasing exposure to gamma radiation, which first affected trees, then shrubs, herbs and, finally, low-growing cushion plants. He concluded that this sequence was the typical pattern to be expected from chronic exposures to serious environmental stresses. Woodwell's generalization, however, may not apply to either this project's aims or to the nature of California mixed conifer forests under oxidant air pollutant stress. This is because certain discrepancies become apparent regarding the perturbation inputs to the system and the system's stress response.

Relation between effects and chronic vs. acute exposure--The differences between chronic and acute exposure and effect, may relate to the source of stress. Woodwell claims that the pattern of vegetation response was evident after only six months' exposure to gamma radiation; compared to other environmental perturbations, the immediacy of this system response could be categorized as acute.

Effect of possible receptor feedback control--Both gamma radiation injury and air pollutant injury to plants are controlled by internal physiological mechanisms which vary with stage of plant development and associated environmental stresses. The mechanisms governing sensitivity to these stresses are different. The dose of gamma radiation was constant in Woodwell's (1970) experiment, but air pollutant dose in nature varies greatly with time. In addition, the mechanism controlling pollutant sensitivity, i.e., transpiration (Mukammal, 1965), may be coupled more strongly to environment than that controlling radiation sensitivity, i.e., rate of cell division. The daily regulation of transpiration and varying oxidant air pollutant doses lead one to expect longer time lags between episodes of pollutant absorption by vegetation and the detectability of resultant injury compared to Woodwell's (1970) gamma radiation study. The dose-response behavior characteristic of pollutant-injured plants suggests that a feed back control mechanism may be operative in SBNF vegetation. We need to know how much pollutant, for a given time, will cause various degrees of growth reduction by age class. We also need this data between, as well as within, species of a plant community.

Ecosystem response under multiple stresses--A longer time lag may allow additional perturbation inputs to arise in the system. During the study period reported by Woodwell in the gamma-radiated forest, no other physical or biological mortality agents were reported to have been imposed on the forest ecosystem. This may be cause, in the forest, gamma radiation is a more direct mortality agent than oxidant air pollutants, which reduce growth rate and overall vigor, enabling other mortality agents to become active among larger tree size classes. Woodwell does not suggest that the causes of observed mortality zones were triggered by another mortality agent during increased weakening of the various life forms by gamma radiation; thus, we must assume that his mortality sequence was simply gamma radiation which killed vegetation.

Under these circumstances, it is questionable that results from the gamma radiation study are similar to responses expected from other forest ecosystems under different types of stresses. In this study of the SBNF, we looked at possible effects from meteorological drought, plant disease, insect outbreaks, fire, and timber harvesting practices concurrent with the stress induced from oxidant air pollution. Levin (1975) stated that " . . .if stability is measured *relative to the set of perturbations to which the system is normally exposed* (a variable criterion by which different systems are compared with respect to different perturbation sets), then such systems show up as more stable" (Italics and parentheses are Levin's).

Rank of species sensitivity and type of stress--Woodwell (1970) does not deal with evidence that ranking inter-species sensitivities to one stress-inducing agent (e.g., oxidant air pollutants) (Miller, 1973) is often different from that species' order of sensitivity to other stress agents (e.g., plant diseases, herbivorous insects, or fire) (Wellner, 1970; Kilgore, 1973).

Response after stress removal--Woodwell's reports (1970, 1975) say nothing about the degree of reversibility (see above, p 75) after the stress agent has been removed. It seems more than fair to challenge Woodwell's claim, based only on his experience with gamma radiation, for the general applicability of his prognosis for ecosystem response to pollutants. The kind of responses and their permanence in conifer forests chronically exposed to oxidant pollutants are yet to be defined.

Empirical Evidence--

Ecological literature is comprised of both descriptive natural history and theoretical analyses whose applicability to real world ecosystems is questionable. Documentary evidence is not available on the irreversibility hypothesis, although one finds the question raised frequently in the research literature (Koenig and Tumala, 1972; Holling, 1974; Edmonds and Sollins, 1974). Bryson and Wendland (1970) claimed that India's arid lands resulted from defoliation and elimination of vegetation which in turn induced local climatic changes not conducive to re-establishing the original vegetation. Charney *et al*. (1975) provided evidence for a similar positive feedback for the Sahara. Glendening (1952) has shown that defoliation stress due to grazing intensity, which then enables tree establishment, will not allow the ecosystem to revert to its previous condition even after stress removal. Holling (1974) discussed evidence of aquatic ecosystems which fail to rejuvenate when stresses are removed. Habeck and Mutch (1973) discussed the likelihood that forest fuel accumulations are so great now because the natural fire frequency has been lowered through fire protection programs, that if these ecosystems were subjected to uncontrolled fire, the heat intensity would be far greater than that to which the systems are evolutionarily adapted. La Chapelle (1967) reported on management attempts to reverse the otherwise irreversible changes in Austrian sub-alpine timberline forest equilibrium resulting from previous logging and grazing activity; these activities have caused a higher frequency of snow avalanche perturbations in this forest ecosystem.

Evidence Supporting the Usefulness and Necessity of Computer Modeling of Ecological Systems--

Conceptual and developmental usefulness for project participants--Innis (1973) defines three stages of usefulness in applying systems modeling methods to environmental research. *Conceptual utility* is derived from the integrated frame of reference provided by an explicity model, or a set of interconnected submodels. *Developmental utility* is the usefulness of the ideas acquired by the team of modeler and field biologists when they assemble the various functional hypotheses comprising a simulation model. A large amount of the published literature on ecological systems simulation is methodology that describes in detail how parts of the system model were constructed, but not what was done with the model after construction. Experimental reports are rare which explain the discoveries made by using the simulator at the ecosystem level. The discoveries, themselves, are accompanied by evidence in the form of displays of simulation experiment results. Both the National Academy of Science (1974) and the National Science Board (1972) provided some evidence of the conceptual and developmental utility of computer simulation modeling in ecosystem research. An interesting discussion of the value to scientists and non-scientists of explicitly exposing assumptions used to construct a simulator appeared in Yorke's discussion in Boling and Van Sickle (1975). Wiegert (1975) demonstrated the clarification of relationship among system components which occurs when working with a simulator. The fact is that using the simulator offers the ability to consider a larger set of ecological variables than any single investigator can observe, and allows collation of various specialists' data sets. A comparison of the team interdisciplinary report by Van Dyne (1972) with the very disciplinary papers in Fries (1974) reveals the difference in levels of system component integration.

Usefulness exported to non-participants--Output utility is the set of data from the computer model performance which is somewhat useful to people not directly involved in the model development. Innis attributed the current relative sparsity of published evidence for output usefulness of ecological simulators to their dependence on a more limited data base than comparable quantitative relations in the physical sciences. Biswas (1975) also presented some reasons and remedies for system simulators' not being used more frequently for environmental management decision-making. An example of one type of output utility -- forecasting of ecosystem responses to trends in environmental stresses -- is found in Giese et al. (1975); this type is central to the objectives of this study (Fig. 22).

Another output utility -- extending the range of relevance of investigations to other locations and/or other years -- was discussed by Goodall (1972). This purpose is shown in the hierarchy of project objectives (Fig. 22), and may be a crucial one. To the extent that system simulators developed for the SBNF can be applied to coniferous forests elsewhere in the western states for making comparative projectives on a geographic scale, we may be able to avoid having this study treated by others simply as an isolated case study for one particular location.

Methods of the System Model Design and Development Process

To design computer simulation models which mimic each subsystem, the project investigators progressed through a sequence of stages for planning, development, and application of systems models (Fig. 23).

After the field monitoring design was established, the investigators explored conceptual models describing the ecosystems (Taylor, 1974). In January, 1975, a system ecologist was added to the project to organize and coordinate the systems modeling effort.

The process of model construction is planned to evolve into a modified form of the "model-oriented, computer-assisted conferencing system" (Kupperman, Wilcox, and Smith, 1975). Two of the principal investigators are located at the University of California, Riverside, and nine are at the University of California, Berkeley. During modeling sessions, a portable computer terminal is carried around for on-line access to a computer center time-sharing system.

Defining Goals for the Eventual Use of System Simulators--

With respect to the stages of modeling (Fig. 23), definition of forecasting goals for the overriding project problem is a critical starting point (Giles, 1972). Two of the objectives (Fig. 22) are to evaluate (1) "the adaptability of these systems models to other pollutant and forest types," and (2) the "consequences of photochemical air pollutants in forest ecosystems on human welfare" (see above p. 72). Thus, we must ascertain that the simulators developed are not customized too exclusively for forecasting conditions unique to the SBNF; they must also be applicable to other similar forest types in the Sierras and elsewhere. Table 10 indicates how various land-use policies for other forests may affect the kind of forest conditions for which we might want forecasts, based on possible future air quality environments.

TABLE 10. POTENTIAL COUPLINGS BETWEEN STRESSED ECOSYSTEM RESPONSES AND SOCIO-POLITICO-ECONOMIC SYSTEMS UNDER VARIOUS FOREST LAND-USE POLICIES.

Ecosystem stresses	Land-use	Ecosystem response	Possible socio-politico-economic impact	
Oxidants Drought Fire Insect spidemic Disease epidemic	Wilderness forests i.e. Wilderness areas USFS National parks NPS	Vegetal and wildlife species composition changes	-Contradiction of legislated policy for land management -Degradation of recreational experience	
	Residential-recreational forests	Dry fuel accumulation	-Fuel reduction costs (private-owner)	
			-Fire control costs	Real estate tax
		Tree canopy decrease	-Flood control costs	Real estate market value
	Multiple-use forests	Game animals	-Hunting	
		Timber production and cut	-Allowable cut lumber cost	
		Forage production and quality	-Grazing permits	

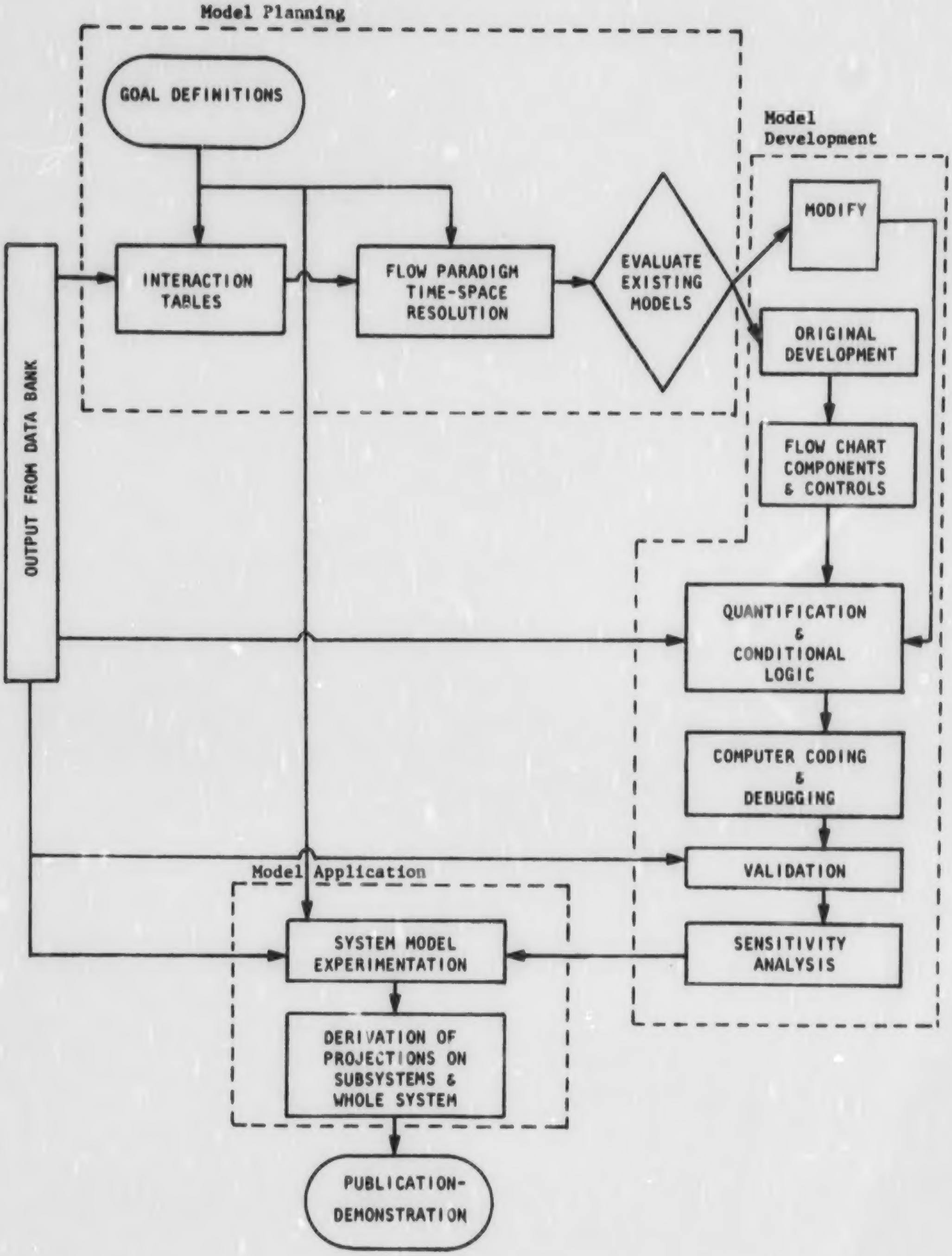

Model Planning
GOAL DEFINITIONS
INTERACTION TABLES
FLOW PARADIGM TIME-SPACE RESOLUTION
EVALUATE EXISTING MODELS
Model Development
MODIFY
ORIGINAL DEVELOPMENT
FLOW CHART COMPONENTS & CONTROLS
OUTPUT FROM DATA BANK
QUANTIFICATION & CONDITIONAL LOGIC
COMPUTER CODING & DEBUGGING
VALIDATION
Model Application
SYSTEM MODEL EXPERIMENTATION
SENSITIVITY ANALYSIS
DERIVATION OF PROJECTIONS ON SUBSYSTEMS & WHOLE SYSTEM
PUBLICATION-DEMONSTRATION

Figure 23. The system simulation modeling process.

We needed to know what kinds of questions the set of system simulation models would be expected to provide answers for, regarding possible future forest conditions. Knowing these would allow examination of the ecosystem-irreversibility question discussed above (pp.73,75). Our immediate question was what might be the effects of various changes in photochemical oxidant air pollutant trends over the next 50 to 100 years, as expressed by (1) number of dead trees per hectare; (2) rate of change in tree species composition for ponderosa and Jeffrey pine. In addition, as a consequence of these two items, we needed to know what vegetation (trees, shrubs, grasses) was likely to maintain or establish an ecologically dominant role in various plant communities now recognized within the California mixed conifer forest type.

Organizaing Subject-Matter Specialists' Ideas into Models--

Our next step (Fig. 23) was to construct interaction tables showing which variables were involved in the various subsystems and decide whether the interaction between any two variables was positive or negative, with an accelerating or decelerating effect. A previous Task D Report (Taylor, 1974) containing various types of interaction diagrams was helpful here.

Next (Fig. 23), we had to select the appropriate paradigm for the substances flowing through the various subsystems: a discussion of various paradigms appeared in Noy-Meir (1973). Possible flows are energy, water, mineral nutrients, biomass, population densities, number of taxonomic species, and area occupied per biotic unit, among others.

Ecosystems can be defined at various spatial scales and for various time scales. In this project, ecosystem simulators are planned for the forest stand-community level. The stand-community ecosystem model may simulate a time period of 50 to 100 years at annual intervals.

Published simulation models (Fig. 23) for ecological systems were reviewed and evaluated to expand upon others' work wherever possible. We used the University of California Center for Information Services (CIS) continually for literature searches in the Cataloging and Indexing System (CAIN) for agriculture; in addition, we used Biological Abstracts (BA) and the Bio-Research Index. Some existing models which we modified for subsystem simulation are indicated below. Flow charts -- graphic representations of subsystem model structures -- were defined, and are being translated into computer code.

Model Quantification and Evaluation Activities Dependent on Availability of a Computerized Data Management System--

Any thorough attempt to study a particular ecosystem will generate large amounts of diverse and highly structured data which need to be collected and stored efficiently. In general the data depend on both the intrinsic properties of the process being measured and the sampling technique employed. A computer processing procedure seemed advisable to handle the large volume of field data we expected to collect.

The types of field data we are collecting can be subdivided into six broad study information classes: meteorological-pollutant dose; vegetation;

arthropods; soils; pathogens; and wildlife. Each of these can be subdivided further into the particular type of data being collected; for example, vegetation information is composed of six different data types. Thus, the data's hierarchical structure mimics that of the SBNF itself.

To process the volume of extremely varied data for the SBNF study, a three year interagency agreement between the Environmental Protection Agency and the Lawrence Livermore Laboratory was initiated on January 1, 1974, for designing and implementing a data management system. The purpose of this system was to collect, store, and process data efficiently and then use it in various subsystem models (Fig. 23). The system ultimately designed for this study is divided into three general sections: data capture, data banking, and data manipulation.

Data capture--Data capture is a collection of techniques used to convert field data into a format suitable for computer storage. Because of the variability in the types of field data being collected, no single data capture scheme can satisfy all field researchers. Therefore, the data capture system should be general enough to accept diverse types of data, which then assumes the dominant role in establishing formats required for entry into the computer system. Once the data are in an acceptable form, they will be stored in a data bank.

The data bank--The data banking system used was designed for the Lawrence Livermore Laboratory, and is called "Master Control" (Hampel and Ramus, 1975). This program was designed to unify storage, and to manipulate, reorganize, retrieve, and display data from dissimilar data bases. It is open-end and user-oriented. Some of its characteristics include: packed memory allocation; hierarchical ordering; using pointers for random access; a telegram-like command language; and options to interrogate and

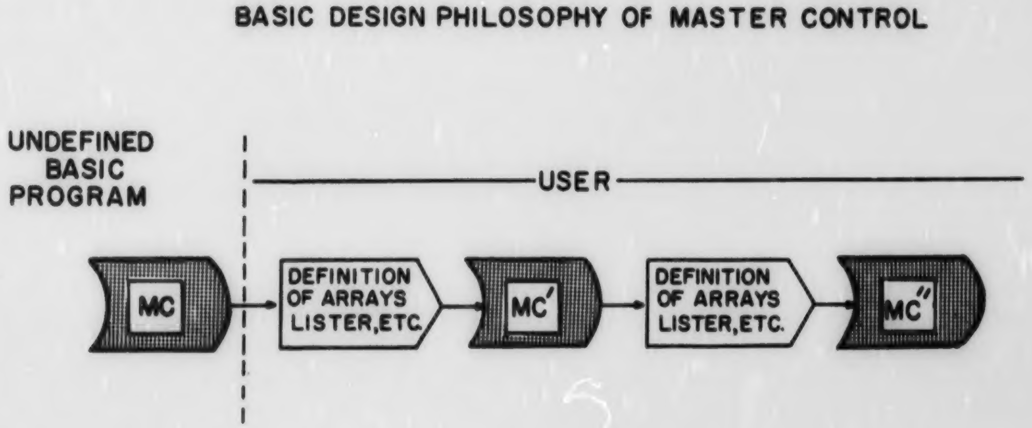

BASIC DESIGN PHILOSOPHY OF MASTER CONTROL
UNDEFINED BASIC PROGRAM
USER
MC
DEFINITION OF ARRAYS LISTER,ETC.
MC′
DEFINITION OF ARRAYS LISTER,ETC.
MC″

Figure 24. Basic design philosophy of "Master Control".

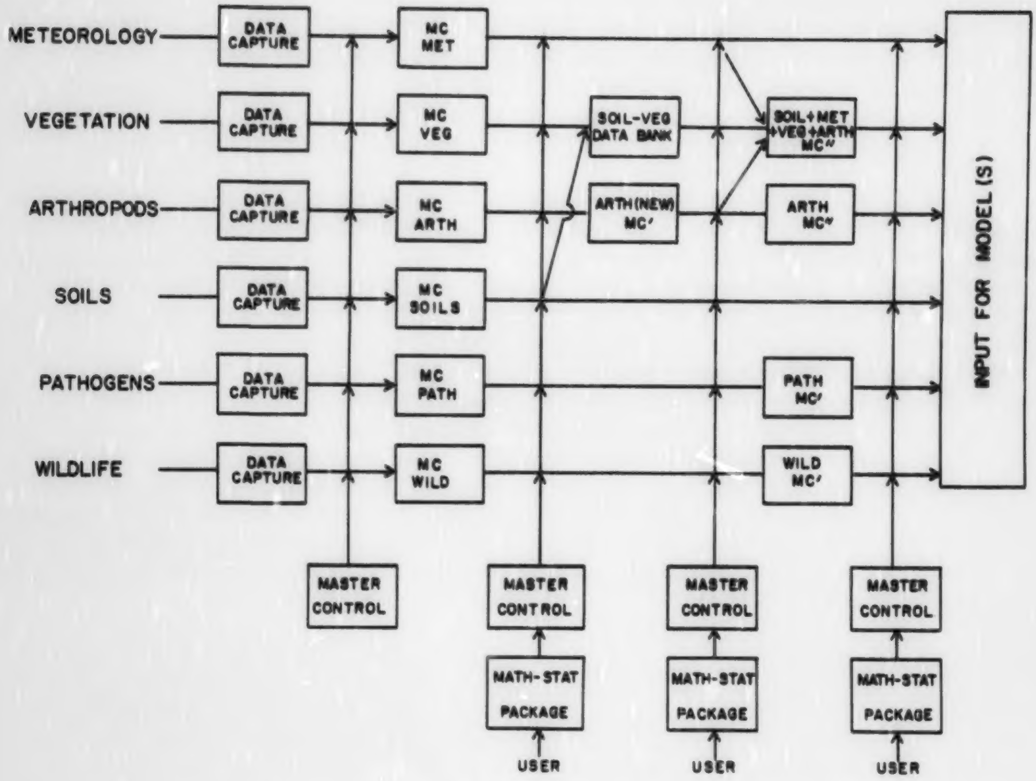

METEOROLOGY
VEGETATION
ARTHROPODS
SOILS
PATHOGENS
WILDLIFE
DATA CAPTURE
DATA CAPTURE
DATA CAPTURE
DATA CAPTURE
DATA CAPTURE
DATA CAPTURE
MC MET
MC VEG
MC ARTH
MC SOILS
MC PATH
MC WILD
SOIL-VEG DATA BANK
ARTH (NEW) MC′
SOIL+MET +VEG+ARTH MC″
ARTH MC″
PATH MC′
WILD MC′
INPUT FOR MODEL (S)
MASTER CONTROL
MASTER CONTROL
MASTER CONTROL
MASTER CONTROL
MATH-STAT PACKAGE
MATH-STAT PACKAGE
MATH-STAT PACKAGE
USER
USER
USER

Figure 25. The San Bernardino Data Management System.

manipulate data bases in both batch or time-share modes. Master Control allows progressive adaptation of data bases to contemporary needs (Fig. 24).

Initially each of the six main field data classes will have its own data bank created by Master Control. Processed field data received from the data capture routines will be stored in each of these banks. Using general command language, we can construct Master Control's new data banks which will reflect user needs (Fig. 25). The command language itself consists of ten general operations: (1) define, (2) initialization, (3) generation, (4) construction, (5) file transfer, (6) alter, (7) edit, (8) search, (9) numerical operations, and (10) macro-operations. Work on applying Master Control to the SBNF study began in April, 1975.

To use the data banking system effectively, it is necessary to provide the user (the modeler(s) or subsystem investigators) with a library of numerical, statistical, and graphical techniques.

Data manipulation--The data manipulation facility of this system contains a library of operational programs which can be used to analyze parts of the data in any given data bank. This facility will reflect the desires indicated by modeling activity, and along with the commands available in Master Control, will provide modeling activity with a method of obtaining data for input into various model development activities.

There are a variety of approaches to designing ecological system models (Jeffers, 1973; Mar, 1974). As a consequence of the diversity in the state-of-the-art, and since field data for this project are being collected on four different classes of observations (nominal, ordinal, interval, and ratio scale), the specific data manipulation procedures have not yet been defined. In general, they will comprise three separate categories of computer programs (Bridges, 1974): (1) graphic display procedures to visually examine graphic plots, spatial maps, response surfaces, and tabularization of observations from field sites and computer model behavior; (2) statistical procedures for use in model design and subsequent model evaluation against the actual landscape ecosystems; and (3) ecological subject data procedures which transcend conventional statistical methods and provide computer analysis capability for analyzing climate, population, biological community, and for calculating ecosystem indices such as species diversity.

Results and Discussion

Progress for this project is described according to the sequence of steps in the simulation modeling process (Fig. 23). Results of this research consist primarily of numerous decisions made while pursuing the three general objectives mentioned above (see "Introduction"). It is still too early to treat results of actual computer experiments using the forest system simulation models.

Progress in the development of this project's simulation modeling process has been governed by several constraints. The principal problem is that a systems modeler was added to the project in January, 1975, whereas the study design and data collection were initiated in 1973. This reverses the most advantageous sequence of events for this type of study; thus it was necessary to attempt to accommodate pre-existing activities to a workable modeling strategy. Specific attention to this task was limited further by a delay in employing a qualified assistant and by limited available office space in which two people could not work efficiently simultaneously. A reliable solution to the office space problem is being sought. Finally, the prime editorial responsibilities for the 1974-75 annual progress report consumed several months. From June through December, 1975, groups of investigators from nine subprojects met for modeling discussions. These meetings helped determine which environmental variables and relationships could be used to structure a model for the various observational and experimental studies being conducted within the entire project. The period from January 1976 to June 1976 was spent synthesizing the information obtained during the previous six months into flow charts for different model subsystems corresponding to the various subprojects. In addition, missing conceptual links between subprojects were corrected as they were revealed in the model discussion sessions.

Hierarchy of Research Problems as Motivating Goals for the Development of Subsystem Simulators--

Relations among problems being explored by systems modeling--From a system viewpoint, some research questions exist above the level of any individual subproject. Such overriding problems must be defined and resolved operationally into a hierarchy of sub-level problems. These, in turn, must correspond to the individual subprojects and their specific objectives. Figure 26 shows the hierarchical structure of problems for the entire project.

In a model such as the one we are developing, the solution of high-level problems depends on the solution of lower-level component problems. This can be interpreted in at least two ways. Any given problem in Figure can be explored through systems simulation only if the next lower level problem is also explored. In addition, any process can be simulated on the computer only if the indicated next lower-level process is simulated. Logical dependency (strategy) is seen from the top down, while tactical operations for time scheduling of research proceed from the bottom up. This explains why the overriding air pollution effects problem cannot be interpreted until after the component subordinate problems have been solved.

Problem Goals, System Model Complexity, and Three Properties of all Simulation Models--

If the overriding problems above all other individual subprojects are to be evaluated (general objective number 3 of the Simulation Modeling subproject), the submodels for all subprojects should be planned at the outset to be dynamically linkable during execution on the computer. It is assumed that this entire project evolved by the conscious direction of the participating research investigators into eleven subprojects. Some of these include investigations so diverse that they actually cover more phenomena than can reasonably be identified as a single subsystem. Such a linking of submodels, in terms of computer programs developed to represent each submodel, becomes a necessary condition for the modeling approach.

We are not attempting to define such a complete, comprehensive, large-scale ecosystem model as many of the biome programs of the U.S. portion of the International Biological Program tried (Mitchell et al., 1976; Boffey, 1976). Rather, our approach emphasizes selected components or processes of the ecosystem which biological specialists define as the most critical to analyzing the transfer of air pollution effects through the forest system. Our model structure is oriented neither toward trophic levels nor energy flow, but is rather a selected food-web structure based on population dynamics paradigms. We use a compartment model approach, where each compartment is usually a population density except in four cases: the water budget subsystem; the litter subsystem (biomass, and percent substrate colonized by fungi); the tree growth subsystem (biomass); and the pathogenic fungi subsystems (percent substrate colonized). Flows between compartments are controlled deterministically by processes, except in the cone production, seedling establishment, and bark beetle subsystem. Part of the end product will be a set of smaller-scale component models of the forest system which are linkable on the computer.

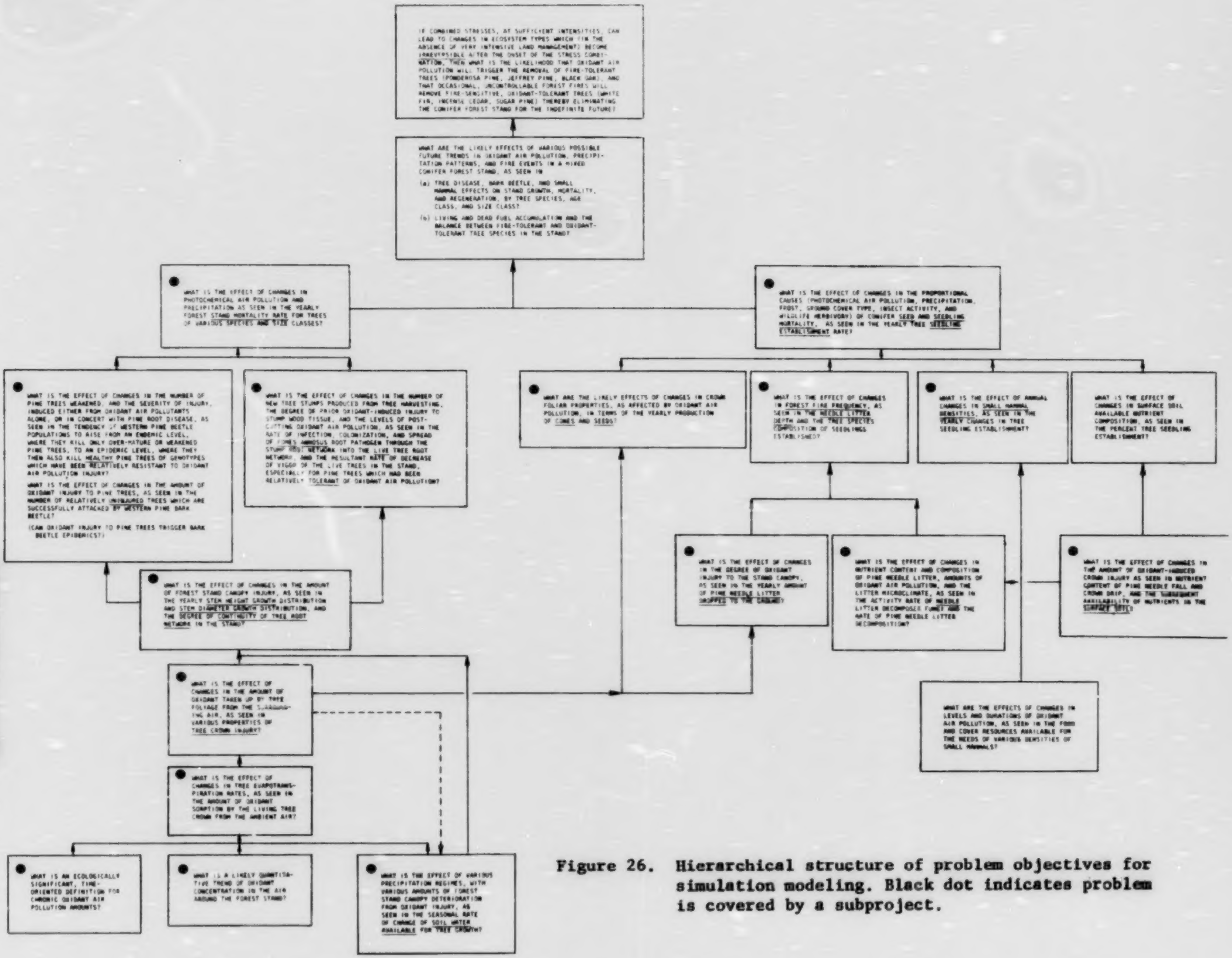

IF COMBINED STRESSES, AT SUFFICIENT INTENSITIES, CAN LEAD TO CHANGES IN ECOSYSTEM TYPES WHICH (IN THE ABSENCE OF VERY INTENSIVE LAND MANAGEMENT) BECOME IRREVERSIBLE AFTER THE ONSET OF THE STRESS COMBINATION, THEN WHAT IS THE LIKELIHOOD THAT OXIDANT AIR POLLUTION WILL TRIGGER THE REMOVAL OF FIRE-TOLERANT TREES (PONDEROSA PINE, JEFFREY PINE, BLACK OAK), AND THAT OCCASIONAL, UNCONTROLLABLE FOREST FIRES WILL REMOVE FIRE-SENSITIVE, OXIDANT-TOLERANT TREES (WHITE FIR, INCENSE CEDAR, SUGAR PINE) THEREBY ELIMINATING THE CONIFER FOREST STAND FOR THE INDEFINITE FUTURE?
WHAT ARE THE LIKELY EFFECTS OF VARIOUS POSSIBLE FUTURE TRENDS IN OXIDANT AIR POLLUTION, PRECIPITATION PATTERNS, AND FIRE EVENTS IN A MIXED CONIFER FOREST STAND, AS SEEN IN
(a) TREE DISEASE, BARK BEETLE, AND SMALL MAMMAL EFFECTS ON STAND GROWTH, MORTALITY, AND REGENERATION, BY TREE SPECIES, AGE CLASS, AND SIZE CLASS?
(b) LIVING AND DEAD FUEL ACCUMULATION AND THE BALANCE BETWEEN FIRE-TOLERANT AND OXIDANT-TOLERANT TREE SPECIES IN THE STAND?
● WHAT IS THE EFFECT OF CHANGES IN PHOTOCHEMICAL AIR POLLUTION AND PRECIPITATION AS SEEN IN THE YEARLY FOREST STAND MORTALITY RATE FOR TREES OF VARIOUS SPECIES AND SIZE CLASSES?
● WHAT IS THE EFFECT OF CHANGES IN THE PROPORTIONAL CAUSES (PHOTOCHEMICAL AIR POLLUTION, PRECIPITATION, FROST, GROUND COVER TYPE, INSECT ACTIVITY, AND WILDLIFE HERBIVORY) OF CONIFER SEED AND SEEDLING MORTALITY, AS SEEN IN THE YEARLY TREE SEEDLING ESTABLISHMENT RATE?
● WHAT IS THE EFFECT OF CHANGES IN THE NUMBER OF PINE TREES WEAKENED, AND THE SEVERITY OF INJURY, INDUCED EITHER FROM OXIDANT AIR POLLUTANTS ALONE, OR IN CONCERT WITH PINE ROOT DISEASE, AS SEEN IN THE TENDENCY OF WESTERN PINE BEETLE POPULATIONS TO RISE FROM AN ENDEMIC LEVEL, WHERE THEY KILL ONLY OVER-MATURE OR WEAKENED PINE TREES, TO AN EPIDEMIC LEVEL, WHERE THEY THEN ALSO KILL HEALTHY PINE TREES OF GENOTYPES WHICH HAVE BEEN RELATIVELY RESISTANT TO OXIDANT AIR POLLUTION INJURY?
WHAT IS THE EFFECT OF CHANGES IN THE AMOUNT OF OXIDANT INJURY TO PINE TREES, AS SEEN IN THE NUMBER OF RELATIVELY UNINJURED TREES WHICH ARE SUCCESSFULLY ATTACKED BY WESTERN PINE BARK BEETLE?
(CAN OXIDANT INJURY TO PINE TREES TRIGGER BARK BEETLE EPIDEMICS?)
● WHAT IS THE EFFECT OF CHANGES IN THE NUMBER OF NEW TREE STUMPS PRODUCED FROM TREE HARVESTING, THE DEGREE OF PRIOR OXIDANT-INDUCED INJURY TO STUMP WOOD TISSUE, AND THE LEVELS OF POST-CUTTING OXIDANT AIR POLLUTION, AS SEEN IN THE RATE OF INFECTION, COLONIZATION, AND SPREAD OF FOMES ANNOSUS ROOT PATHOGEN THROUGH THE STUMP ROOT NETWORK INTO THE LIVE TREE ROOT NETWORK, AND THE RESULTANT RATE OF DECREASE OF VIGOR OF THE LIVE TREES IN THE STAND, ESPECIALLY FOR PINE TREES WHICH HAD BEEN RELATIVELY TOLERANT OF OXIDANT AIR POLLUTION?
● WHAT ARE THE LIKELY EFFECTS OF CHANGES IN CROWN FOLIAR PROPERTIES, AS AFFECTED BY OXIDANT AIR POLLUTION, IN TERMS OF THE YEARLY PRODUCTION OF CONES AND SEEDS?
● WHAT IS THE EFFECT OF CHANGES IN FOREST FIRE FREQUENCY, AS SEEN IN THE NEEDLE LITTER DEPTH AND THE TREE SPECIES COMPOSITION OF SEEDLINGS ESTABLISHED?
● WHAT IS THE EFFECT OF ANNUAL CHANGES IN SMALL MAMMAL DENSITIES, AS SEEN IN THE YEARLY CHANGES IN TREE SEEDLING ESTABLISHMENT?
WHAT IS THE EFFECT OF CHANGES IN SURFACE SOIL AVAILABLE NUTRIENT COMPOSITION, AS SEEN IN THE PERCENT TREE SEEDLING ESTABLISHMENT?
● WHAT IS THE EFFECT OF CHANGES IN THE DEGREE OF OXIDANT INJURY TO THE STAND CANOPY, AS SEEN IN THE YEARLY AMOUNT OF PINE NEEDLE LITTER DROPPED TO THE GROUND?
● WHAT IS THE EFFECT OF CHANGES IN NUTRIENT CONTENT AND COMPOSITION OF PINE NEEDLE LITTER, AMOUNTS OF OXIDANT AIR POLLUTION, AND THE LITTER MICROCLIMATE, AS SEEN IN THE ACTIVITY RATE OF NEEDLE LITTER DECOMPOSER FUNGI AND THE RATE OF PINE NEEDLE LITTER DECOMPOSITION?
● WHAT IS THE EFFECT OF CHANGES IN THE AMOUNT OF OXIDANT-INDUCED CROWN INJURY AS SEEN IN NUTRIENT CONTENT OF PINE NEEDLE FALL AND CROWN DRIP, AND THE SUBSEQUENT AVAILABILITY OF NUTRIENTS IN THE SURFACE SOIL?
WHAT ARE THE EFFECTS OF CHANGES IN LEVELS AND DURATIONS OF OXIDANT AIR POLLUTION, AS SEEN IN THE FOOD AND COVER RESOURCES AVAILABLE FOR THE NEEDS OF VARIOUS DENSITIES OF SMALL MAMMALS?
● WHAT IS THE EFFECT OF CHANGES IN THE AMOUNT OF FOREST STAND CANOPY INJURY, AS SEEN IN THE YEARLY STEM HEIGHT GROWTH DISTRIBUTION AND STEM DIAMETER GROWTH DISTRIBUTION, AND THE DEGREE OF CONTINUITY OF TREE ROOT NETWORK IN THE STAND?
● WHAT IS THE EFFECT OF CHANGES IN THE AMOUNT OF OXIDANT TAKEN UP BY TREE FOLIAGE FROM THE SURROUNDING AIR, AS SEEN IN VARIOUS PROPERTIES OF TREE CROWN INJURY?
● WHAT IS THE EFFECT OF CHANGES IN TREE EVAPOTRANSPIRATION RATES, AS SEEN IN THE AMOUNT OF OXIDANT SORPTION BY THE LIVING TREE CROWN FROM THE AMBIENT AIR?
● WHAT IS AN ECOLOGICALLY SIGNIFICANT, TIME-ORIENTED DEFINITION FOR CHRONIC OXIDANT AIR POLLUTION AMOUNTS?
● WHAT IS A LIKELY QUANTITATIVE TREND OF OXIDANT CONCENTRATION IN THE AIR AROUND THE FOREST STAND?
● WHAT IS THE EFFECT OF VARIOUS PRECIPITATION REGIMES, WITH VARIOUS AMOUNTS OF FOREST STAND CANOPY DETERIORATION FROM OXIDANT INJURY, AS SEEN IN THE SEASONAL RATE OF CHANGE OF SOIL WATER AVAILABLE FOR TREE GROWTH?

Figure 26. Hierarchical structure of problem objectives for simulation modeling. Black dot indicates problem is covered by a subproject.

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Although we have considered three other alternative model development strategies, they are unacceptable for the following reasons. The first alternative is to develop "stand-alone" models, one for each subproject, none of which could be dynamically linked during a computer simulation run. In this case, the overall research program would lose its integrative nature and more importantly, computer models could not be used directly to address the higher-level research problems (Fig. 26) which transcend all individual subprojects. At the beginning of the entire project (1972-1973), data collection designs were constructed so that a component subproject model would sometimes require driving data input from one, or several, different component models of the other subprojects; consequently, linkages were very strongly inherent in the data collection designs of some of the subprojects even before initiation of formal system modeling work in January, 1975.

The second alternative is to link some (but not all) subprojects models as an operating unit. However, this strategy cannot be used when the project has only one investigator responsible for computer model development: some subprojects ineivitably would be ignored by the modeling effort for their irrelevance to the particular system model designed for the "select" subprojects. Decisions like these would probably be in direct proportion to the modeler's background in the subject matter disciplines of the various subprojects. Also, it should raise the issue of why the E. P. A. would support certain subprojects without any attempt to synthesize their research results into computer models with forecast capability. Results of the 1976 Environmental Modeling and Simulation Conference (Ott, 1976) suggest that the E. P. A.'s expectation from modeling is a complete simulation of the systems under investigation.

The third alternative is to include all subproject results within a single integrative set of ecological models defined so that each subproject scientist could use only 2 or 3 variables to describe his biological processes in the project-wide simulation model. It is likely, however, that to force this unilateral constraint on the subject matter specialists would place both the scientist's and the model's credibility in jeopardy. The specialists and the systems ecologist would have to agree on the level of biological realism necessary to define the critical components of the system being studied.

All quantitative models possess different degrees of the three following general properties: realism, generality, and precision. However, no single model can maximize all three properties (Levins, 1966). This subproject's priorities for these model properties are:

1) realism. It is important to structure the model components as subject matter specialists presently conceive of them.

2) generality. There must be sufficient similarity to other forest ecosystems which could be subject to oxidant pollutant injury at some future date. Examples include the western slope of the Wasatch mountains, the eastern slope of the Rocky mountains, and the western slope of the Sierra Nevada mountains.

3) precision. Only limited levels of precision are possible because of the limitations of the present state of knowledge; on the other hand, models must try for the highest level of biological reality without becoming unmanageable.

Description and Flow Chart of Forest System Model--

Dependence between subsystems--Correspondences may be see among the subsystem models being developed as a linked set of simulation models (Fig. 27) and the hierarchy of research problems shown in Figure 26. Figure 27 may be used as a guide to find a particular subsystem defined in greater graphic detail in Figure 28. Figure 28 shows how the investigators have conceptualized the various component subsystems which they think are critical to studying the ecological effects of oxidant air pollutants in the forest. In addition, observable variables used to define entities in each subsystem are shown. Although we will eventually publish a task- or procedure-oriented flow chart as part of the description of the algorithmic logic currently being developed to simulate this system structure, Figure 28 is a flow chart of how the system is conceived of as being dynamically structured. It is different from the task- or procedure-oriented chart.

At the base of this set of ecological systems models is a population dynamics accounting for live trees in the forest stand by species. The reason for the circles in Figure 28, labeled "Source" and "Sink" is that we are not conceptualizing a biomass cyclical system; this would be necessary in a carbon or nutrient cycle model. Rather, we are often invoking a population dynamics approach in which population increases come from an undefined source and are eventually sent to an undefined sink. Both terms are modeling abstractions. The rates at which entities flow from a source, or alternatively into a sink, are controlled by other tangible biological and environmental variables or site parameters. All of the subsystems contribute to defining the calculation of new trees added to the stand, by species, or the number of living trees killed in the stand.

Word model of the linked subsystems--Only a word model will be described for the intersubsystem level (Fig. 27). Detailed word model descriptions, mathematical documentation, and computer programs for the logic within each of the subsystem models (Fig. 28) will be presented in subsequent reports. This is because the detailed logic at the level of Figure 28 is presently being evaluated using data and results from the various subprojects.

In the order that the various subsystem models will be described, the following names are being used for the respective computer routines: STANDCMP (Tree Population Dynamics); TREEGROW (Tree Growth); SEED (Cone and Seed Production); ROOTS (Root Pathogen Dynamics); BEETLE (Pine Bark Beetle Population Dynamics); CANOPY (Oxidant Air Pollutant Flux-Canopy Response); WATER (Stand Moisture Dynamics); MICROCLI (Microclimate); SEEDLING (Seedling establishment); LITTER (Litter Production); LITDECAY (Fine Litter Decay); WOODECAY (Woody Litter Decay); and RODENT (Small Mammal Population Dynamics).

Both stand regeneration and mortality are partially controlled by tree

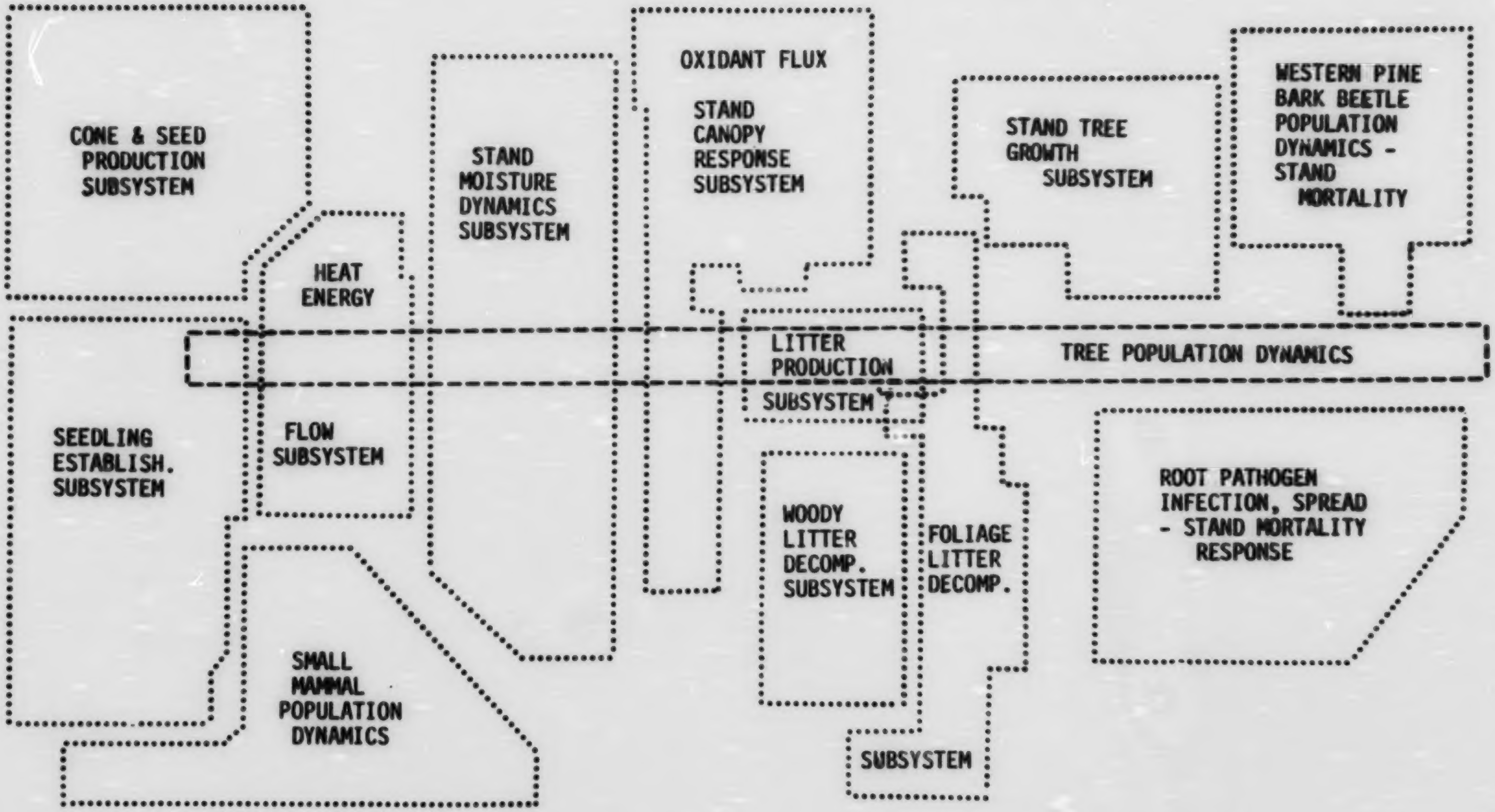
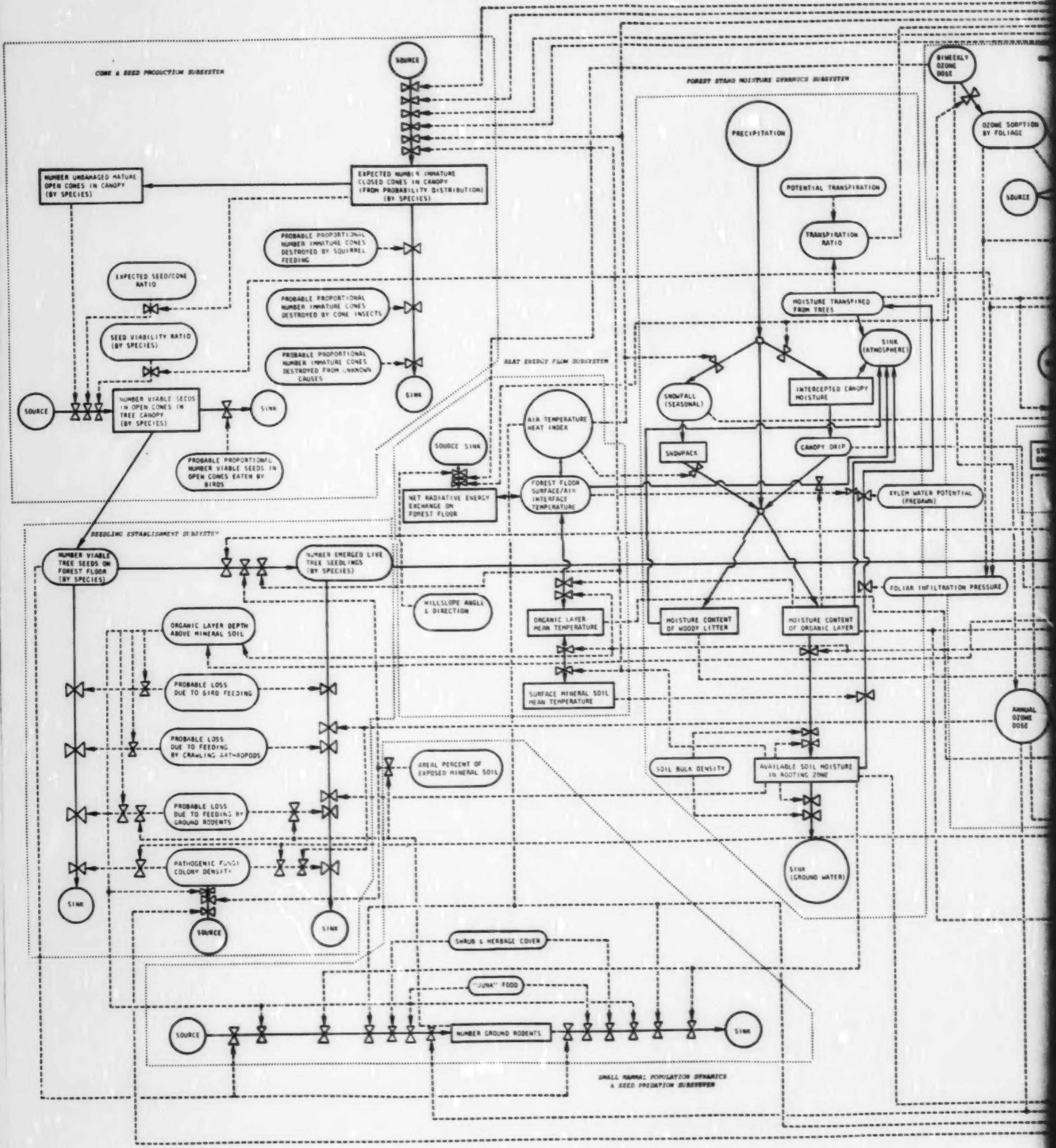
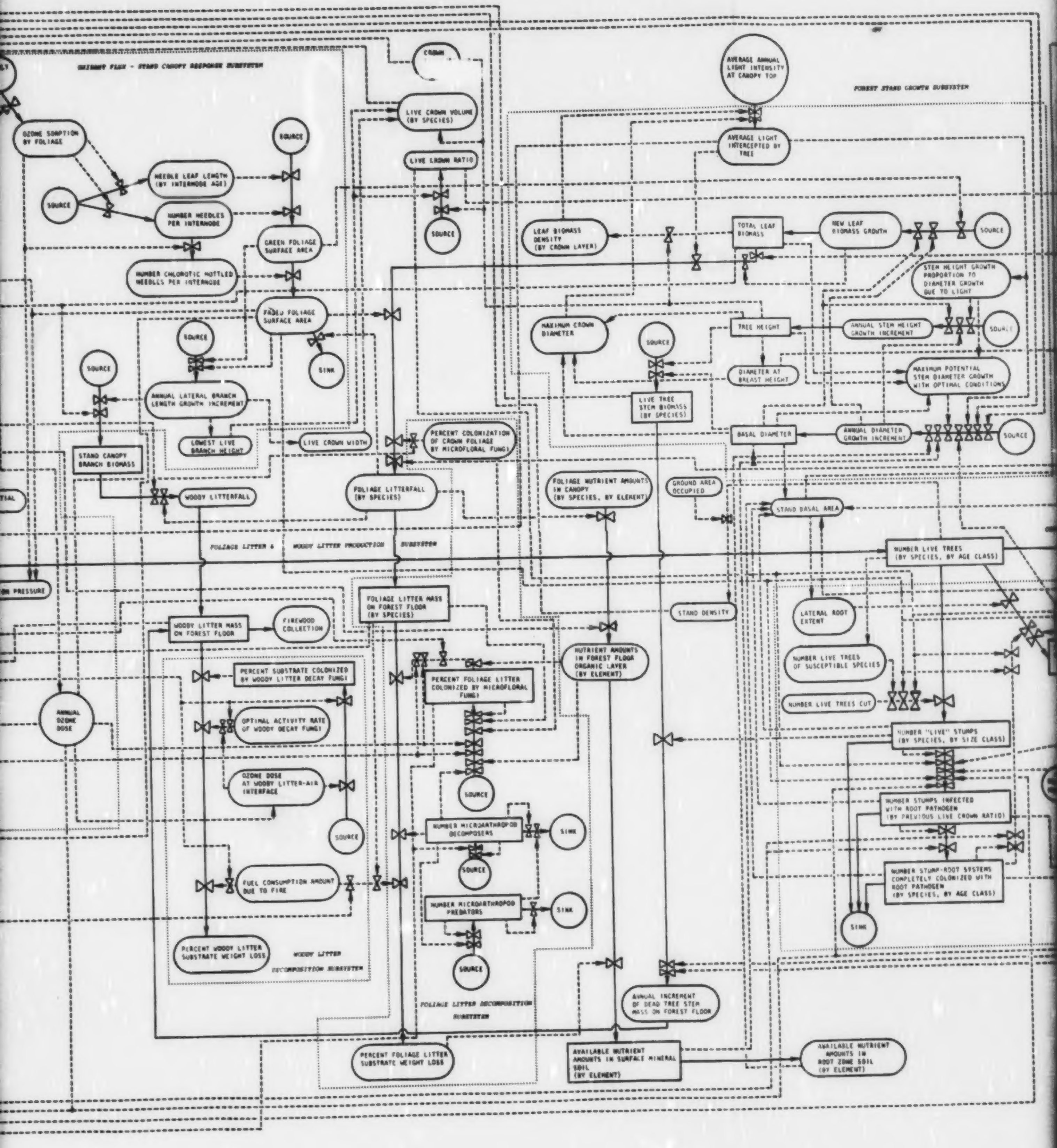

CONE & SEED PRODUCTION SUBSYSTEM
SEEDLING ESTABLISH. SUBSYSTEM
HEAT ENERGY
FLOW SUBSYSTEM
SMALL MAMMAL POPULATION DYNAMICS
STAND MOISTURE DYNAMICS SUBSYSTEM
OXIDANT FLUX
STAND CANOPY RESPONSE SUBSYSTEM
LITTER PRODUCTION SUBSYSTEM
WOODY LITTER DECOMP. SUBSYSTEM
FOLIAGE LITTER DECOMP.
SUBSYSTEM
STAND TREE GROWTH SUBSYSTEM
WESTERN PINE BARK BEETLE POPULATION DYNAMICS - STAND MORTALITY
TREE POPULATION DYNAMICS
ROOT PATHOGEN INFECTION, SPREAD - STAND MORTALITY RESPONSE

Figure 27. Guide to subsystems.


CONE & SEED PRODUCTION SUBSYSTEM
SOURCE
NUMBER UNDAMAGED MATURE OPEN CONES IN CANOPY (BY SPECIES)
EXPECTED NUMBER IMMATURE CLOSED CONES IN CANOPY (FROM PROBABILITY DISTRIBUTION) (BY SPECIES)
PROBABLE PROPORTIONAL NUMBER IMMATURE CONES DESTROYED BY SQUIRREL FEEDING
EXPECTED SEED/CONE RATIO
PROBABLE PROPORTIONAL NUMBER IMMATURE CONES DESTROYED BY CONE INSECTS
SEED VIABILITY RATIO (BY SPECIES)
PROBABLE PROPORTIONAL NUMBER IMMATURE CONES DESTROYED FROM UNKNOWN CAUSES
SINK
SOURCE
NUMBER VIABLE SEEDS IN OPEN CONES IN TREE CANOPY (BY SPECIES)
SINK
PROBABLE PROPORTIONAL NUMBER VIABLE SEEDS IN OPEN CONES EATEN BY BIRDS
HEAT ENERGY FLOW SUBSYSTEM
SOURCE SINK
AIR TEMPERATURE HEAT INDEX
NET RADIATIVE ENERGY EXCHANGE ON FOREST FLOOR
FOREST FLOOR SURFACE/AIR INTERFACE TEMPERATURE
FOREST STAND MOISTURE DYNAMICS SUBSYSTEM
PRECIPITATION
POTENTIAL TRANSPIRATION
TRANSPIRATION RATIO
MOISTURE TRANSPIRED FROM TREES
SINK (ATMOSPHERE)
SNOWFALL (SEASONAL)
INTERCEPTED CANOPY MOISTURE
SNOWPACK
CANOPY DRIP
XYLEM WATER POTENTIAL (PREDAWN)
BIWEEKLY OZONE DOSE
OZONE SORPTION BY FOLIAGE
SOURCE
SEEDLING ESTABLISHMENT SUBSYSTEM
NUMBER VIABLE TREE SEEDS ON FOREST FLOOR (BY SPECIES)
NUMBER EMERGED LIVE TREE SEEDLINGS (BY SPECIES)
HILLSLOPE ANGLE & DIRECTION
ORGANIC LAYER MEAN TEMPERATURE
MOISTURE CONTENT OF WOODY LITTER
MOISTURE CONTENT OF ORGANIC LAYER
FOLIAR INFILTRATION PRESSURE
ORGANIC LAYER DEPTH ABOVE MINERAL SOIL
SURFACE MINERAL SOIL MEAN TEMPERATURE
PROBABLE LOSS DUE TO BIRD FEEDING
PROBABLE LOSS DUE TO FEEDING BY CRAWLING ARTHROPODS
AREAL PERCENT OF EXPOSED MINERAL SOIL
SOIL BULK DENSITY
AVAILABLE SOIL MOISTURE IN ROOTING ZONE
ANNUAL OZONE DOSE
PROBABLE LOSS DUE TO FEEDING BY GROUND RODENTS
PATHOGENIC FUNGI COLONY DENSITY
SINK
SOURCE
SINK
SINK (GROUND WATER)
SHRUB & HERBAGE COVER
"JUNK" FOOD
SOURCE
NUMBER GROUND RODENTS
SINK
SMALL MAMMAL POPULATION DYNAMICS & SEED PREDATION SUBSYSTEM


OZONE FLUX - STAND CANOPY RESPONSE SUBSYSTEM
CROWN
OZONE SORPTION BY FOLIAGE
SOURCE
NEEDLE LEAF LENGTH (BY INTERNODE AGE)
NUMBER NEEDLES PER INTERNODE
SOURCE
GREEN FOLIAGE SURFACE AREA
NUMBER CHLOROTIC MOTTLED NEEDLES PER INTERNODE
FADED FOLIAGE SURFACE AREA
SINK
LIVE CROWN VOLUME (BY SPECIES)
LIVE CROWN RATIO
SOURCE
SOURCE
SOURCE
ANNUAL LATERAL BRANCH LENGTH GROWTH INCREMENT
LOWEST LIVE BRANCH HEIGHT
LIVE CROWN WIDTH
STAND CANOPY BRANCH BIOMASS
WOODY LITTERFALL
TIAL
PERCENT COLONIZATION OF CROWN FOLIAGE BY MICROFLORAL FUNGI
FOLIAGE LITTERFALL (BY SPECIES)
FOLIAGE LITTER & WOODY LITTER PRODUCTION SUBSYSTEM
ON PRESSURE
FOLIAGE LITTER MASS ON FOREST FLOOR (BY SPECIES)
WOODY LITTER MASS ON FOREST FLOOR
FIREWOOD COLLECTION
PERCENT SUBSTRATE COLONIZED BY WOODY LITTER DECAY FUNGI
ANNUAL OZONE DOSE
OPTIMAL ACTIVITY RATE OF WOODY DECAY FUNGI
OZONE DOSE AT WOODY LITTER-AIR INTERFACE
SOURCE
FUEL CONSUMPTION AMOUNT DUE TO FIRE
PERCENT WOODY LITTER SUBSTRATE WEIGHT LOSS
WOODY LITTER DECOMPOSITION SUBSYSTEM
PERCENT FOLIAGE LITTER COLONIZED BY MICROFLORAL FUNGI
SOURCE
NUMBER MICROARTHROPOD DECOMPOSERS
SINK
SOURCE
NUMBER MICROARTHROPOD PREDATORS
SINK
SOURCE
FOLIAGE LITTER DECOMPOSITION SUBSYSTEM
PERCENT FOLIAGE LITTER SUBSTRATE WEIGHT LOSS
AVERAGE ANNUAL LIGHT INTENSITY AT CANOPY TOP
FOREST STAND GROWTH SUBSYSTEM
AVERAGE LIGHT INTERCEPTED BY TREE
LEAF BIOMASS DENSITY (BY CROWN LAYER)
TOTAL LEAF BIOMASS
NEW LEAF BIOMASS GROWTH
SOURCE
STEM HEIGHT GROWTH PROPORTION TO DIAMETER GROWTH DUE TO LIGHT
MAXIMUM CROWN DIAMETER
TREE HEIGHT
ANNUAL STEM HEIGHT GROWTH INCREMENT
SOURCE
SOURCE
DIAMETER AT BREAST HEIGHT
MAXIMUM POTENTIAL STEM DIAMETER GROWTH WITH OPTIMAL CONDITIONS
LIVE TREE STEM BIOMASS (BY SPECIES)
BASAL DIAMETER
ANNUAL DIAMETER GROWTH INCREMENT
SOURCE
FOLIAGE NUTRIENT AMOUNTS IN CANOPY (BY SPECIES, BY ELEMENT)
GROUND AREA OCCUPIED
STAND BASAL AREA
NUMBER LIVE TREES (BY SPECIES, BY AGE CLASS)
STAND DENSITY
LATERAL ROOT EXTENT
NUTRIENT AMOUNTS IN FOREST FLOOR ORGANIC LAYER (BY ELEMENT)
NUMBER LIVE TREES OF SUSCEPTIBLE SPECIES
NUMBER LIVE TREES CUT
NUMBER "LIVE" STUMPS (BY SPECIES, BY SIZE CLASS)
NUMBER STUMPS INFECTED WITH ROOT PATHOGEN (BY PREVIOUS LIVE CROWN RATIO)
NUMBER STUMP-ROOT SYSTEMS COMPLETELY COLONIZED WITH ROOT PATHOGEN (BY SPECIES, BY AGE CLASS)
SINK
ANNUAL INCREMENT OF DEAD TREE STEM MASS ON FOREST FLOOR
AVAILABLE NUTRIENT AMOUNTS IN SURFACE MINERAL SOIL (BY ELEMENT)
AVAILABLE NUTRIENT AMOUNTS IN ROOT ZONE SOIL (BY ELEMENT)

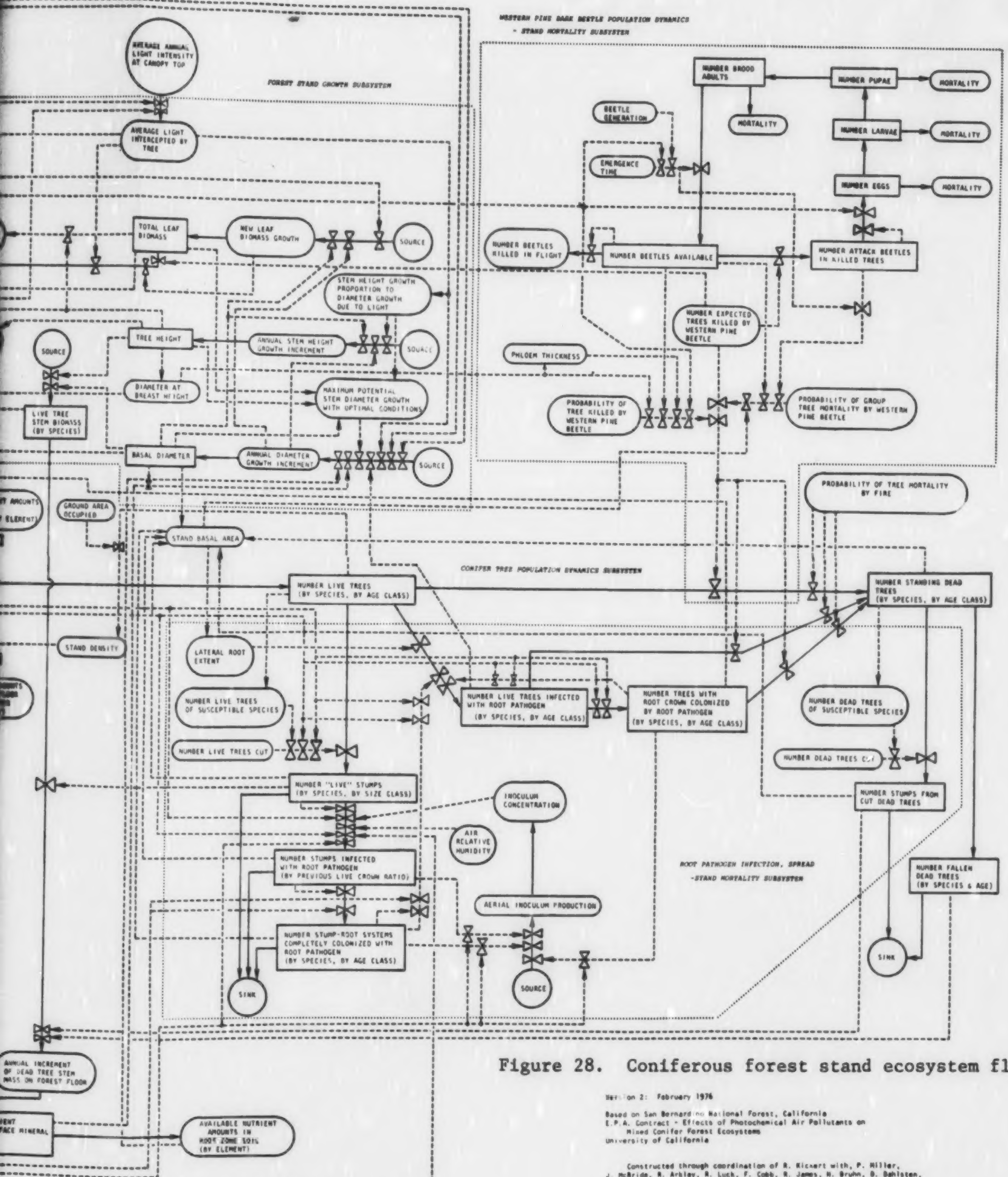

WESTERN PINE BARK BEETLE POPULATION DYNAMICS
- STAND MORTALITY SUBSYSTEM
AVERAGE ANNUAL LIGHT INTENSITY AT CANOPY TOP
FOREST STAND GROWTH SUBSYSTEM
AVERAGE LIGHT INTERCEPTED BY TREE
TOTAL LEAF BIOMASS
NEW LEAF BIOMASS GROWTH
SOURCE
STEM HEIGHT GROWTH PROPORTION TO DIAMETER GROWTH DUE TO LIGHT
TREE HEIGHT
ANNUAL STEM HEIGHT GROWTH INCREMENT
DIAMETER AT BREAST HEIGHT
MAXIMUM POTENTIAL STEM DIAMETER GROWTH WITH OPTIMAL CONDITIONS
LIVE TREE STEM BIOMASS (BY SPECIES)
BASAL DIAMETER
ANNUAL DIAMETER GROWTH INCREMENT
GROUND AREA OCCUPIED
STAND BASAL AREA
NUMBER BROOD ADULTS
NUMBER PUPAE
MORTALITY
BEETLE GENERATION
EMERGENCE TIME
NUMBER LARVAE
NUMBER EGGS
NUMBER BEETLES KILLED IN FLIGHT
NUMBER BEETLES AVAILABLE
NUMBER ATTACK BEETLES IN KILLED TREES
NUMBER EXPECTED TREES KILLED BY WESTERN PINE BEETLE
PHLOEM THICKNESS
PROBABILITY OF TREE KILLED BY WESTERN PINE BEETLE
PROBABILITY OF GROUP TREE MORTALITY BY WESTERN PINE BEETLE
PROBABILITY OF TREE MORTALITY BY FIRE
CONIFER TREE POPULATION DYNAMICS SUBSYSTEM
NUMBER LIVE TREES (BY SPECIES, BY AGE CLASS)
NUMBER STANDING DEAD TREES (BY SPECIES, BY AGE CLASS)
STAND DENSITY
LATERAL ROOT EXTENT
NUMBER LIVE TREES OF SUSCEPTIBLE SPECIES
NUMBER LIVE TREES INFECTED WITH ROOT PATHOGEN (BY SPECIES, BY AGE CLASS)
NUMBER TREES WITH ROOT CROWN COLONIZED BY ROOT PATHOGEN (BY SPECIES, BY AGE CLASS)
NUMBER DEAD TREES OF SUSCEPTIBLE SPECIES
NUMBER LIVE TREES CUT
NUMBER DEAD TREES CUT
NUMBER "LIVE" STUMPS (BY SPECIES, BY SIZE CLASS)
INOCULUM CONCENTRATION
NUMBER STUMPS FROM CUT DEAD TREES
AIR RELATIVE HUMIDITY
NUMBER STUMPS INFECTED WITH ROOT PATHOGEN (BY PREVIOUS LIVE CROWN RATIO)
ROOT PATHOGEN INFECTION, SPREAD
-STAND MORTALITY SUBSYSTEM
NUMBER FALLEN DEAD TREES (BY SPECIES & AGE)
AERIAL INOCULUM PRODUCTION
NUMBER STUMP-ROOT SYSTEMS COMPLETELY COLONIZED WITH ROOT PATHOGEN (BY SPECIES, BY AGE CLASS)
SINK
ANNUAL INCREMENT OF DEAD TREE STEM MASS ON FOREST FLOOR
AVAILABLE NUTRIENT AMOUNTS IN ROOT ZONE SOIL (BY ELEMENT)

Figure 28. Coniferous forest stand ecosystem flow chart.

Version 2: February 1976

Based on San Bernardino National Forest, California
E.P.A. Contract - Effects of Photochemical Air Pollutants on
Mixed Conifer Forest Ecosystems
University of California

Constructed through coordination of R. Kickert with, P. Miller, J. McBride, R. Arkley, R. Luck, F. Cobb, R. James, N. Bruhn, D. Dahlsten, R. Swift, J. Barbieri, J.R. Parmeter, J. Bruhn, J. Wenz, D. Rowney, W. Wilcox, H. White, S. Sweetwood, with modifications to a few subsystem models produced elsewhere by R. Reed, P. Sollins, R.H. Waring and D. W. Cole population density by species (STANDCMP) and rates of tree growth (TREEGROW). The latter subsystem simulates the diameter and height growth distributions for trees in the stand and provides dynamic regulation on how large the cone crop may be for potential regeneration of new trees in the (SEED). Tree population density and tree growth rate also regulate how likely trees are to be: (1) cut down, either to provide stumps for root-disease development or to regulate tree-to-tree spread of the established root pathogen through the live standing trees (ROOTS); and (2) attacked and killed by bark beetles (BEETLE). As trees are killed by these processes, they are removed from the system state which describes how many live trees of a given species are present at a given time interval. STANDGROW is controlled primarily by the CANOPY, WATER, and very simplified MICROCLI which simulates light and heat available for tree growth. CANOPY simulates various crown injury symptoms as a consequence of the uptake of oxidants from the air into the foliage. This process is controlled by the rate of flow of water through the system as simulated by WATER.

Brief mention has been made of regeneration for mature tree population dynamics as controlled by (SEED) which is partly regulated by rates of tree growth and the degree of air pollution-induced crown injury. Regeneration is further simulated with a population dynamics model for seedlings (SEEDLING). Input is simulated seedfall from SEED, and loss is due to seed and seedling mortality which, in terms of other subsystems shown in Figure 28, are controlled by (1) the amount of organic litter lying above mineral soil (LITTER), (2) herbivory by small mammals (RODENT), and (3) the surface soil moisture (WATER). The first of these is simulated as a balance between (LITTER) providing the input, and (LITDECAY) and (WOODECAY) simulating the reduction of organic litter on the ground. The principal crown symptom of oxidant injury is an increase in the rate of fall of foliage from the crowns of sensitive conifer species. Three intersubsystem controls have important regulatory influences. The first is the behavior of the CANOPY Subsystem that regulates the LITTER Subsystem. The second, herbivory, is controlled by a subsystem simulation of small mammal population dynamics (RODENT). The third intersubsystem control is through linkage with the WATER Subsystem already mentioned in conjunction with the TREEGROW Subsystem above.

Two of these submodels will not originate with this project, but will be modifications of simulators developed elsewhere. There include the Stand Tree Growth Simulator (Reed, 1976; Reed and Clark, 1976), a transpiration simulator (Reed and Waring, 1974), and the Stand Moisture Dynamics Simulator (Sollins, 1974).

An overview of these linked subsystem models reveals certain inputs that any potential user will be expected to provide and there are certain primary outputs which are of central interest to air quality effects analysts and the control-policy decision-makers whom they serve. The primary inputs are:

1) oxidant/ozone concentration

2) precipitation

3) net radiation

4) air temperature

5) relative humidity

Primary outputs are:

1) number of live trees (by species and age)

2) number of standing dead trees (by species)

3) number of tree seedlings (by species) surviving 3 years

4) number of trees (by species) killed by root disease

5) number of trees (by species) killed by bark beetles

6) distribution of tree basal diameters in the stand (by species)

7) distribution of tree heights in the stand (by species)

8) distribution of breast-height diameters of trees in the stand

9) mass of foliage litter on the ground

Future Application and Limitations--

The models are designed primarily to explore possible consequences of alternative environmental quality control strategies, particular of air quality. This concept centers on controlling an input to the forest ecosystem. The ecosystem response categories of forest resource production management and forest protection management are of central concern to the production-oriented land and wildlife management agencies. It is our view that the basic structure of this set of models is applicable in forest recreation management and timber management.

Resource potentials which are not expected to be considered by this set of models for air pollution effects question involve three areas: watershed management, forage-livestock management, and wildlife management. The first of these limitations exists because we are modeling a forest system at the stand level, and not at the watershed level. Consequently, the stream is treated as a sink into which we route the stand's soil and ground water. We focus on the depletion of soil water, rather than on stream flow. We are not using a daily water budget simulation. This implies that the WATER subsystem will not provide any output on the timing, quantity, and quality of stream water, information that would be needed to answer watershed management questions.

The second limitation exists because of our current inability to simulate understory vegetation dynamics. This is due to the lack of appropriate data. The third limitation, however, is only partially valid. Management of wildlife in a forest under air pollutant stress may be served indirectly by information on a given animal's habitat, namely, live and dead tree species composition and abundance, and seed abundance. The only wildlife planned for explicity modeling in this system are small mammals.

In terms of forest protection management, the set of models will be addressable on a limited scale to fire management, insect pest management, and forest disease management under conditions of air pollutant stress.

Spatial Aspects of Submodels Compared to Field Plot Data--

Forest stand level--It is possible to define a forest ecological system model at a number of different spatial scales. An early progress report (Taylor, 1974) indicated that several different scales were being used informally as a frame of reference for various subprojects. We argued, however, that one modeler could not efficiently coordinate the various subprojects to design forest models at several spatial scales simultaneously. The E. P. A. project officer suggested that E. P. A.'s needs would be served better by a forest-stand-level model. For simulation purposes, we interpret a stand as comprising anywhere from 10 to 200 trees, primarily conifers; the equivalent land area may range from about 100 m^2 to about 25,000 m^2.

Field Plot Biological Complexity versus Model Structure--

Eighteen vegetation plots had been established in the SBNF between 1968 and 1974, before the beginning of formal systems analysis and modeling. The decision to design a forest-stand-level simulation model had to be reviewed for certain pre-existing conditions, which were determined by the site suitability and vegetation cover at the 18 plots. The central question was whether data already collected from these plots could be used to quantify a stand-level simulation model. The plots ranged in size from 0.21 ha (UCC) to 1.80 ha (SCR and GVC) and, with the assumption that a plot could be treated as a forest stand, we discovered a wide range in percent species composition of oxidant-sensitive tree species and in percent shrub cover on the plots (Fig. 29) (this was subsequently found to be untenable). The assumption is that the lower the number of oxidant sensitive trees, the greater expectation of biological competition for resources by relatively oxidant-tolerant tree species (incense cedar, sugar pine, black oak). The higher the shrub cover, the greater the biological competition exerted by the shrub layer on trees in the community.

Four of the 18 plots (BF, UCC, CAO and CA) offered the greatest simplicity of stand ecosystem model structure. They may be suitable for either model development or model application for a stand model dealing with the population dynamics of only one tree species and do not require any shrub dynamics (Fig. 29, upper left).

The next level of complexity for 11 of the 18 plots (SF, TUN2, DW, SCR, CP, BP, DL, GVC, BL, COO, and SC) required a model structure dealing with more than one tree species. It especially required one dealing with differing tolerances to oxidant air pollutants, but with no shrub layer within the simulated stand (Fig. 29, lower left). This presents some

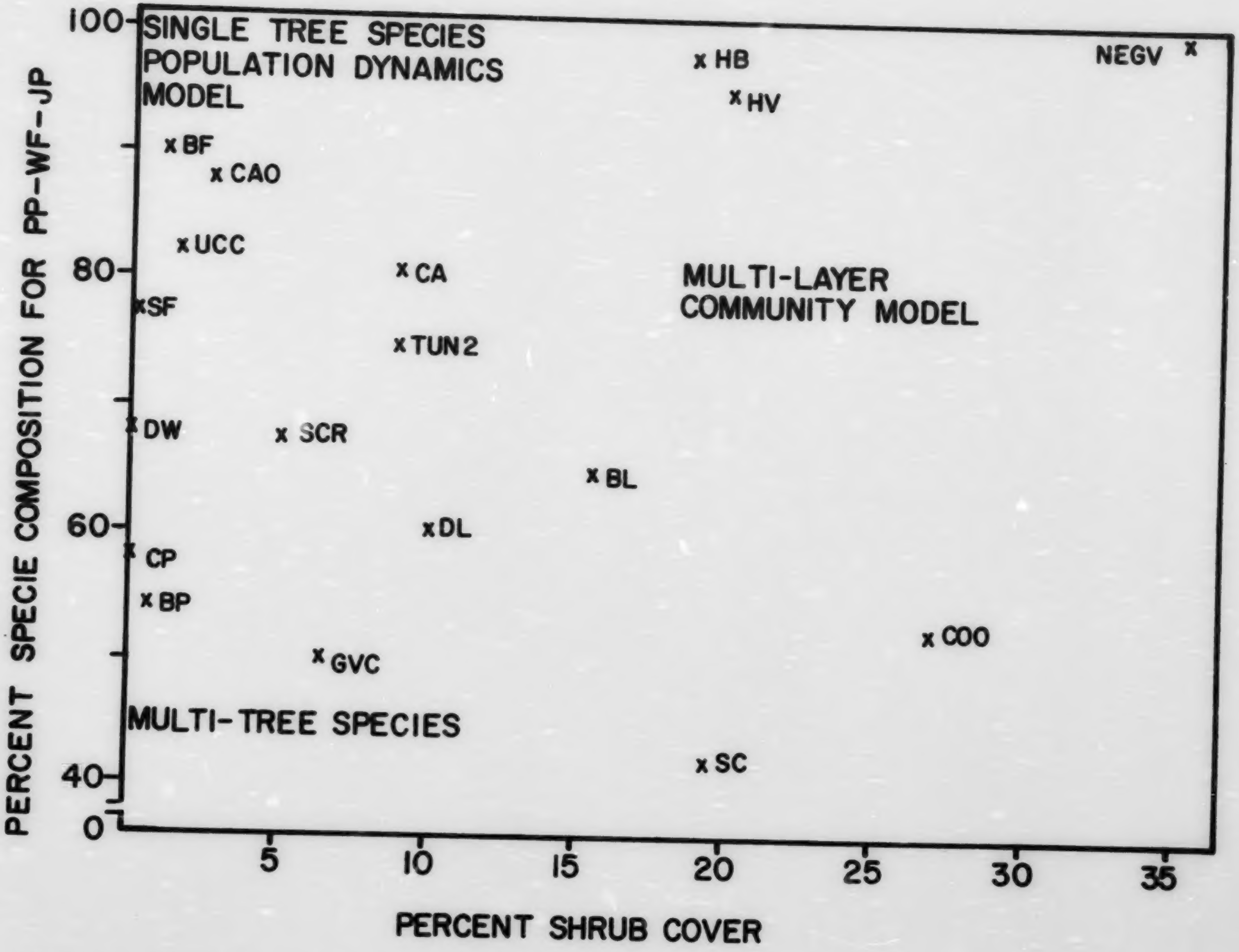


Figure 29. Difference of 18 permanent vegetation plots when compared as the percent specieis composition of oxidant air pollutant sensitive tree species (ponderosa and Jeffrey pine and white fir as a group) vs. percent shrub cover.

problems for quantification since a number of biological process studies in various subprojects have been confined to variables involving ponderosa and Jeffrey pines only. These include bark beetles and root pathogen in stand mortality, and seedling establishment, litter production and litter decomposition with regard to stand regeneration.

The complexity rises another level when we see from Figure 29 (right) that 6 (HB, HV, NEGV, BL, SC, and COO) of the 18 plots have greater than 15% shrub cover. This implies that, besides being able to quantify and simulate the dynamics of more than one tree species simultaneously, we must also model the dynamics of the shrub component of the forest stand. The present data on shrubs is too meager to permit this. We cannot assume effects on trees are not influenced by shrub competition, especially on a plot having 36% shrub cover (NEGV, Fig. 29). We have omitted from this discussion that other understory life forms such as herbage and ferns are present. If effects of these understory components were included in the system structure, then it would be necessary to prescribe the increases and decreases occurring in the herb layer over time.

The Use of Different Field Plots for Mortality and Regeneration for Model Building and Model Validation--

The 18 permanent vegetation plots were not selected at random. The first criterion was the presence of at least 50 ponderosa or Jeffrey pines in size classes larger than 30 cm dbh. The next most important factors were slope, aspect, and soil type. There was no conscious effort to avoid any of the physical disturbances, such as logging, or locations where biological pest complexes were active on any overstory species. The tremendous diversity which is now a problem when modeling is attempted is simply a reflection of existing conditions. The absence of some biological agents responsible for the death of mature trees is to be expected because they are very spatially discontinuous. If one used the 18 plots alone, the activity of pests would be seriously underestimated because of the small plot size. For this reason, the data from 18 permanent vegetation plots are being used mainly for those biological subsystem models pertaining to tree growth, canopy response, and litter regeneration. This partially excludes the two subsystems which directly control mature tree mortality: the root disease subsystem and the bark beetle subsystem. These two will be developed and subsequently validated on the basis of data collected from "mortality centers." These are plots defined around recently killed and/or extremely injured trees, as determined from a combination of recent air photo interpretation and ground measurement of stand-, oxidant injury-, bark beetle-, and disease-related variables (McBride et al., 1976). The 18 permanent plots and the mortality centers are, therefore, two separate sets of plots, and are used for separate, although linked subsystem models in the total simulation modeling effort.

Within each of these two sets of plots, one stratification which must be made for systems modeling purposes at the outset is to define (1) which plot areas shall be used to develop and quantify subsystem models, and (2) which plot areas shall be "reserved" for validating the subsystem models against the real world. It is a commonly accepted principle among ecological modelers that data which have been used to construct a computer simulation model cannot, and should not, be subsequently used (Fig. 23) to compare how well the model performs with respect to the real world. While it is too early to decide how a group of mortality centers will be reserved for validating the two mature-tree mortality-related submodels, we will reserve 30 m^2 sections of each of the 18 permanent vegetation plots to validate the non-mortality subsystem models, but with a particular caveat. At least 4 of these plots show signs of genetic cross-breeding resulting in hybridization between ponderosa and Jeffrey pine, and between ponderosa and Coulter pine. Since other mixed conifer forests (for example, in the Sierra Nevada) do not produce the same degree of hybridization (Luck, personal communication), and since one of our objectives is to produce models which can be used outside the SBNF for assessing ecological effects of air pollution, we have decided that certain plots (CAO, BF, GVC, and maybe TUN2) must be regarded very suspiciously with respect to data analysis for modeling.

Aside from the two sets of field study plots mentioned, some research has been done on three additional distinct sets of plots: 24 sapling plots, 85 fire plots, and 22 aspect plots. Since the status of data entry into the computerized data management system for these plots is delayed, we have not made any plans to immediately use such data for modeling purposes. This information will be requested from the relevant project investigators in the near future.

The next decision we faced was how to establish the conceptual spatial boundaries of a forest stand ecosystem with regard to the spatial properties of subsystem components. To avoid excessive complexity in model structure, we are treating the effect of spatial heterogeneity in terms of areal densities for the stand area as a unit, rather than distance-dependence relations within the stand area. We realize we depart from reality in doing this since mature tree mortality and natural tree seedling establishment do not occur homogeneously or continuously in horizontal space across the forest. Rather, spatial clumping is evident especially on those plots where either oxidant-sensitive tree species composition is lower, or shrub cover is higher (Fig. 29).

Treatment of Time in Submodels Compared to Field Data Collection--

The time span to be simulated on the computer by running the set of models ranges from 20 to 50 years as a user-selectable option. Since most of the quantitative data collection effort which will establish the parameters of transfer functions in the models is based upon annual observations, most of the subsystems will simulate on a yearly time step. However, there are a few exceptions. Biweekly time steps are planned for the following subsystem models: MICROCLI, WATER, and CANOPY. The BEETLE submodel is planned to cycle at 4-month increments. For the remaining submodels -- SEED, SEEDLING, LITTER, LITDECAY, WOODECAY, RODENT, TREEGROW, ROOTS, and STANDCMP -- it is assumed that inter-seasonal and/or intraseasonal changes which can occur are unimportant for estimating forest ecosystem response under oxidant air pollutant stress over the medium-term (20 to 50 year simulation time span). The same conclusion is assumed for all submodels for time frequencies greater than biweekly (i.e., weekly, diurnally, hourly).

Proportional Causes and Rates of Mature Tree Mortality Under Varying Air Pollutant Stress--

While the biological details of a root pathogen and several bark beetle species were being studied, it became evident that we would not be able to link the information for either of these possible mortality causes to the population dynamics of trees at a forest-stand-level. We did not have data on the variable degree of importance of different possible mortality agents for mature trees. Both the small area size and the locations of the 18 permanent vegetation plots became suspect in terms of providing data on stand mortality rates and relative importance of different causes of mortality. Analysis of data from forest-wide mortality centers will correct this problem.

Proportional Causes of Tree Seed and Seedling Mortality in Stands Receiving Varying Air Pollutant Stress--

Different subprojects examined various processes controlling the establishment of tree seedlings, such as seedling growth with respect to air pollution levels, changes in needle litter and duff depths, abundance and dietary patterns of herbivorous small mammals, activity of damping-off fungi, and seasonal soil moisture depletion. To simulate the regeneration of new trees into the stand population, however, we needed to know what proportion of potential tree seedling establishement is prevented by various mortality agents. The above data gathering activities have been consolidated by Cobb (see the above seedling establishment section).

Data for Tree Growth Submodel for Stands Receiving Varying Air Pollutant Stress--

Several of the subsystems required input to other subsystems on various tree biomass or yield properties under varying air pollutant stress. Some of the subsystems requiring this information are those for cone production, root pathogen infection and spread, and pine bark beetle population dynamics. Through June, 1976, there was insufficient programming of tree growth data collection (and analysis) to allow stand growth modeling which would provide the needed inputs to these other subsystems.

Preparation of Historical Data Sets for Eventual Computer Model Validation Analysis--

Before a simulator is applied to some need, it should have its behavior on the computer compared to the behavior of that portion of the real world that it represents. This step has often been labeled "validation," although the question of whether any model can be considered "valid" at all (Wiegert, 1975) has recently become a controversial issue among systems ecologists. If we can initially set the ecosystem simulator for ca. 1940 and run it up through 1974, we should be able to compare the tree species composition resulting on the computer with that observed by McBride (1973), as a form of "validation." In addition, historical data on physical processes are needed to construct stochastic driving variable generators for the exogenous inputs to the subsystem models. Such historical data which could be very useful include meteorological data from agency files, fire history data (especially on the 18 permanent vegetation plots), insect-pest tree damage records, and possibly certain timber-harvesting records for determining annual stump production as possible root pathogen infection centers. There is also a need to establish techniques whereby earlier trends in oxidant air pollution concentrations can be established.

Process-Oriented Foliar Injury Modeling--

In an attempt to quantify the responses of various foliage properties to photochemical air pollution conditions, a "Smog injury index" has been developed and has gone through several stages of evolution (Stark et al., 1968; Miller, 1973; Miller, 1974). During mid-1975, we recognized that the ordinal-scale mathematical definition of the index, while relatively simple operationally, was inappropriate (Batschelet, 1971) to subsequent quantitative analysis techniques (e.g., statistical regression) which requires data on interval or ratio-scale-defined variables. The index may be useful for purely descriptive purposes for forest managers, but it is not defensible for purposes of ecological functional analysis.

Within Plot Heterogeneity and Data Analysis Noise--

In June, 1976, we became aware of the extent of ground cover-soil-physiography spatial heterogeneity on 12 of the 18 permanent vegetation plots. Plot data analyzed for model building on a per-unit-area basis would contain a great deal of noise for such plots unless within-plot areal stratification could be done on a natural basis. Data on the spatial variation of soil types, hillslope gradient and aspect are needed within plots.

Remote Terminal Graphic Display Procedure--

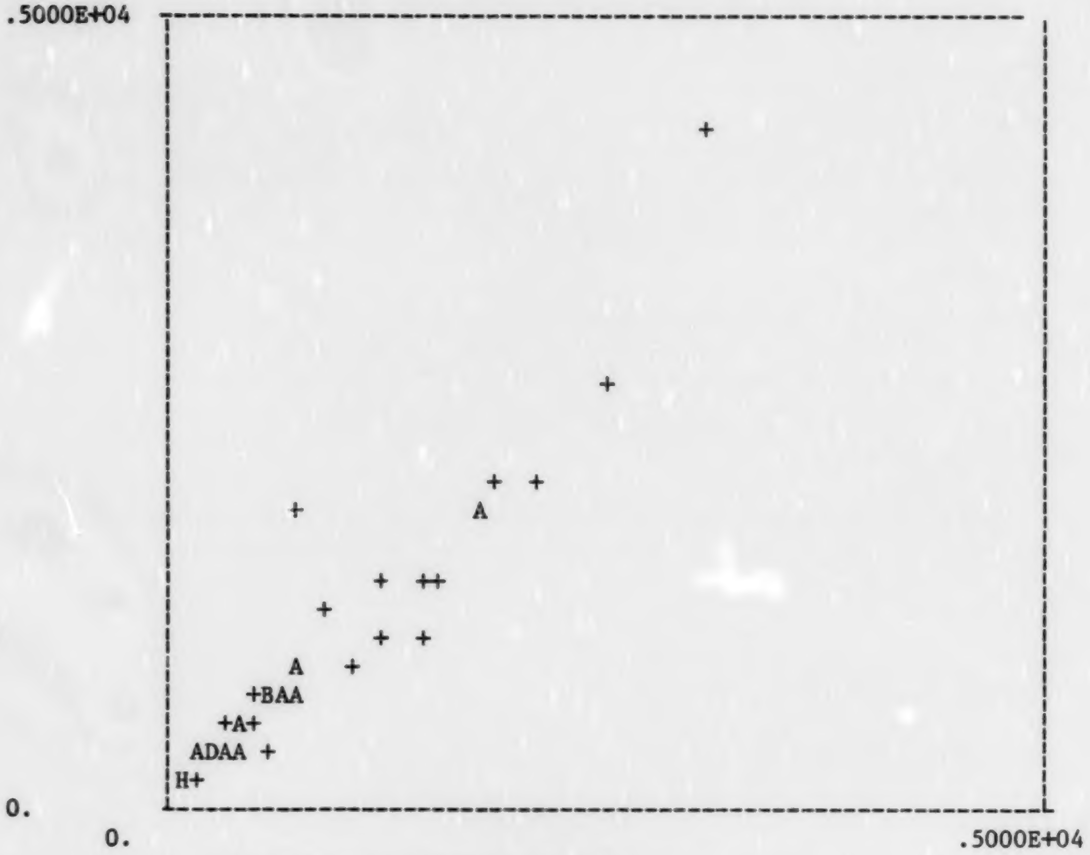
Computer centers have numerous library programs which may be used to display data graphically. Often, these are formated for line-printer line widths but are not easily reduced to accommodate narrower dimensions for output on Teletype-like remote terminals. In order to have such on-line graphing procedures immediately available as we move into that phase of model development where we resume frequent modeling sessions with various subject-matter specialists, we have modified a number of graphing routines originally developed in the U.S. International Biological Program--The Desert Biome.

PUTCUR is a graphing routine that accepts data as input and produces output as graphs. The user controls the format of the output, sets limits for X and Y, and either (1) designates the computer file from which data are taken, or (2) enters the data from the terminal keyboard. He controls these functions by his responses to questions displayed at the terminal. The first option can be used when an investigator is retrieving data from the data bank.

PUTCUR prints a graph fifty print positions wide by twenty-five print lines high. The plotting symbol is "+" for each data coordinate pair.

For Scatter Charts (Fig. 30), the Multiple-Occurrence option plots "+" for a single occurrence, "A" for two occurrences, "B" for three, and so on to "Z" for twenty-seven or more occurrences.

```
E
NUMBER OF VALUES TO BE PLOTTED = 50
```



```
          MULTIPLE OCCURANCE INDICATION
"+" =  1 Occurance,  "A" = 2, "B" = 3, . . . , Z = 27 or more

JANUARY RAINFALL   1931-1975
    X = Squirrel Inn #2
    Y = Lake Arrowhead Fire
```

Figure 30. Example of PUTCUR graphic data display for exploratory data analysis.

For Line Graphs, the Asterisk Interpolation option adds "*" symbols between plotted points.

For uniform scale, maximum and minimum can be set for X and Y using the Set X, Set Y option. If an X, Y pair has either or both values outside the set limits, it will be ignored. If no limits are set, the X and Y limits will be determined by the minimum and maximum X and Y values entered.

Data can be entered from the keyboard as integers, with or without an explicit decimal, will be in scientific notation, and may be either positive or negative. If the data are entered from a computer file, a retrieval program is required to assemble them into an array which is passed to the PUTCUR program.

PRTPLT is an output data diaplay subroutine for graphing simulation model behavior on the terminal along the length of the paper (Fig. 31). Therefore, it is only limited theoretically by the length of paper on the roll.

Progress and Problems in Data Management Procedures--

In contrast to all of the other subprojects, the ecosystem simulation modeling subproject does not collect any laboratory or field data. As Figure 23 indicates, the ecological systems modeling process is very dependent upon the degree of user-oriented efficiency of a computerized data management system.

Both the rate at which data collected from the various subprojects are entered into the data management system, and the subsequent ease with which we can gain access to those data determine the rate at which system simulation models can be quantified, and the rate at which we can move toward model validation analysis, reliability test, or other comparison of the computer model performance with real world behavior (Fig. 23).

Data capture development--For the SBNF project, a fieldfree format input was developed in which field data were not required to appear in specific columns on a data sheet. By allowing the field researcher to design his own data sheets, we hoped that the amount of error in handling data would be minimized. The data capture system designed for the SBNF study notes inconsistencies and then ignores them: such data are simply not processed. Therefore, instead of rejecting whole data sets because of an error in any one of them, the data capture system records the error and then processes what is acceptable.

The data capture system itself is divided into three types of computer routines: (1) executive and library routines, (2) operational routines, and (3) decoding routines. The executive routines contain not only all of the general logic for determining the type of data being entered but also a library of all names and mnemonics used by any of the operational routines. The decoding routines are responsible for decoding and classifying actual data into integers, floating point numbers, alphabetic character(s), and/or special symbols. The operational routines

```
GRAPH OF CFB WATER MODEL BEHAVIOR
SYMBOL    MINIMUM               GRAPHING                   MAXIMUM
  P      0.           PRECIP       .US.     DAY          .5000E+02
  T      -.1000E+02   AIR TEMP     .US.     DAY          .2500E+02
  L      -.1000E+02   LIT TEMP     .US.     DAY          .2500E+02
  1      0.           FOLIAR       .US.     DAY          .3000E+03
  2      0.           SNOW         .US.     DAY          .5000E+04
  3      0.           ROOT ZONE    .US.     DAY          .5000E+04
  5      0.           STREAM       .US.     DAY          .5000E+03
  7      0.           LITTER       .US.     DAY          .5000E+01
DAY   PRECI
  1    0.00  7     T           L                3 5                       .
  2    0.00  7     T  5        L                3                         .
  3    0.00  7 5   T           L                3                         .
  4    0.00  7     T           L               3                          .
  5    0.00  7     T           L               3                          .
  6    0.00  7     T           L               3                          .
  7    0.00  7     T           L               3                          .
  8    0.00  7     T           L              3                           .
  9    0.00  7     T           L              3                           .
 10    0.00  7     T           L              3                           .
 11    0.50  7     T           L              3                           .
 12    0.50  7 2   T          L              3                            .
 13    0.50  7  2  T          L              3                            .
 14    0.50  7   2 T          L              3                            .
 15    0.50  7    2T          L              3                            .
 16    0.50  7     T2         L              3                            .
 17    0.50  7     T 2        L             3                             .
 18    0.50  7     T   2      L             3                             .
 19    0.50  7     T    2     L             3                             .
 20    0.50  7     T     2    L             3                             .
 21    0.50  7     T      2   L            3                              .
 22    0.50  7     T        2 L            3                              .
 23    0.50  7     T          2            3                              .
 24    0.50  7     T          L  2         3                              .
 25    0.50  7     T          L    2      3                               .
 26    0.50  7     T          L       2   3                               .
 27    0.50  7     T          L          23                               .
 28    0.50  7     T          L           32                              .
 29    0.50  7     T          L          3  2                             .
 30    0.50  7     T          L          3    2                           .
 31    0.50  7     T          L          3      2                         .
 32    0.50  7     T          L          3        2                       .
 33    0.50  7     T          L          3          2                     .
 34    0.50  7     T          L         3             2                   .
 35    0.50  7     T          L         3               2                 .
 36    0.50  7     T          L         3                 2               .
 37    0.50  7     T          L         3                   2             .
 38    0.50  7     T          L        3                      2           .
```

Figure 31. Example of PRTPLT graphic data display for output of system model behavior.

determine whether the data is in an acceptable format and then stores it into given locations for future use. A schematic diagram for the arthropod data capture system is given in Figure 32. Presently, the data capture system is capable of accepting twenty different field data types.

Each operational subroutine will have the capability to summarize and statistically analyze the incoming field data. These capabilities are determined by the requirements of the user. At present, there are eight summation routines coded.

Inefficient accessibility to the LLL computer--While computer implementation of the various subsystem models (Fig. 27) discussed previously were planned to be accomplished by June, 1977, in many cases this had to be done by using hypothetical data. There are frequent problems in using the Lawrence Livermore Laboratory computer from a dial-up remote location, and initial data capture of datasets involves a time delay due to keypunching of card decks.

From June, 1975 to June, 1976, the ecosystem simulation subproject has used the Burroughs 6700 computer via the CANDE time-sharing system by telephone from Berkeley to the U.C. San Diego Computer Center. The reasons for our having to use such a distant computer were: (1) absence of an academic-based computer center in the San Francisco Bay Area having remote, conversational time-sharing capability with interactive programming option; and (2) at the U.C. Davis campus computer center the lack of abundant software compared to that UCSD. In spring 1976, we began trying to access the LLL computer center by telephone in order to process certain data sets for model-building purposes. Remote-terminal telecommunication was discovered to be more cumbersome, transmission rate was 3 times slower (10 cps), unanticipated time-delays were far more prevalent, and time-sharing command logic was far less conversational on the LLL computer system than they were on the U.C.S.D. computer. This created insurmountable problems in terms of ease (and, therefore, rate) of data processing ability by this and many of the other subprojects. Experience has shown that after one has learned the fundamentals of computer operation, one knows he is on the wrong computer system when he finds himself waiting for the computer instead of finding the computer waiting for him, as occurs on a user-efficient time-sharing system. In recognition of this, an attempt will be made to export the computerized data management system to the new IMB 370/145 computer at the U.C. San Francisco Medical Center Computer Center, in the latter half of 1976. This computer system supports a time-sharing system called Conversational Monitor System (CMS), and appears able to provide the kind of computer resources needed by the entire project to link the Simulation Modeling subproject and the Data Management System subproject on the same computer system. Also needed is simple and easy, direct, on-line access for any project investigators to the data management system, as a daily, routine procedure. If modeling activity progress is to be achieved, it is imperative that the data management system become completely operational for all data sets through the "data manipulation phase" by January, 1977, at the latest.

Inefficient methods of field data entry into computer readable

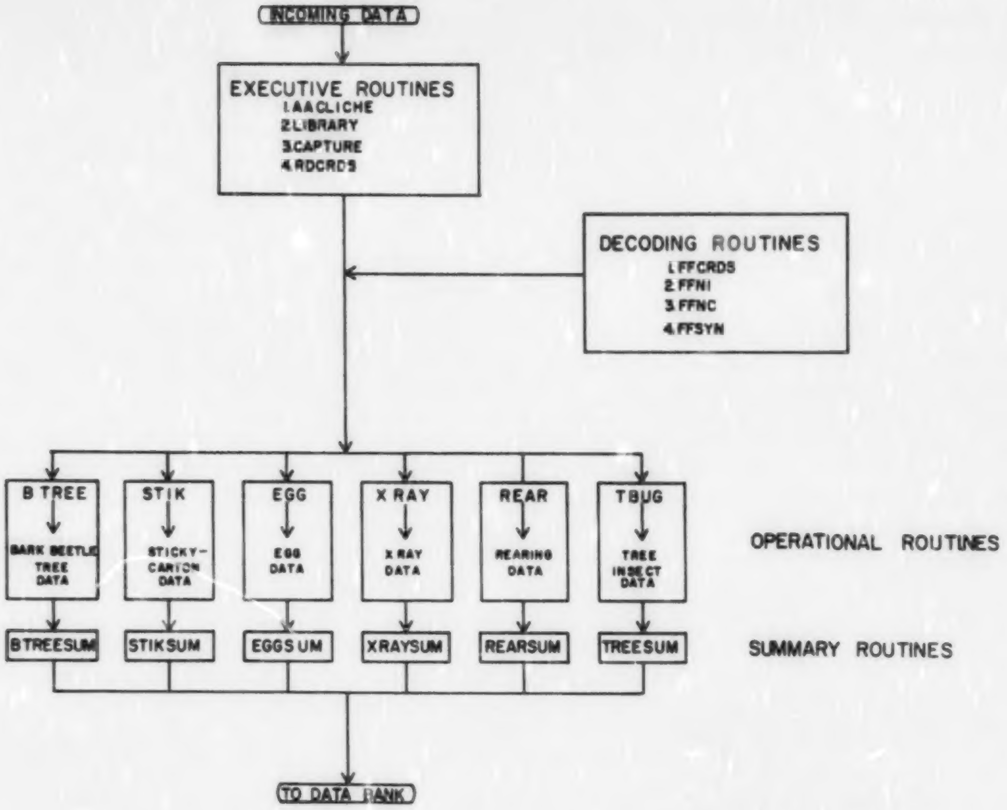
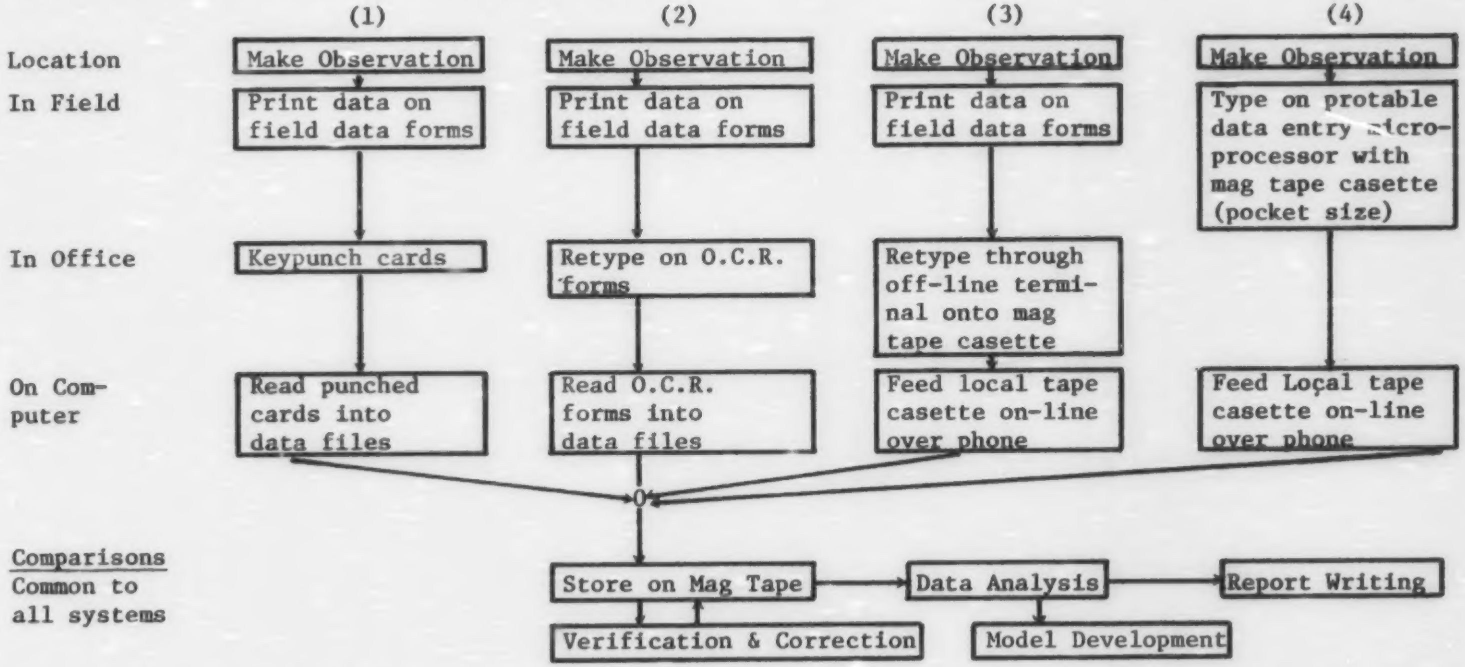

INCOMING DATA
EXECUTIVE ROUTINES
1. AACLICHE
2. LIBRARY
3. CAPTURE
4. RDCRDS
DECODING ROUTINES
1. FFCRDS
2. FFNI
3. FFNC
4. FFSYN
B TREE
BARK BEETLE TREE DATA
STIK
STICKY-CARTON DATA
EGG
EGG DATA
X RAY
X RAY DATA
REAR
REARING DATA
TBUG
TREE INSECT DATA
OPERATIONAL ROUTINES
BTREESUM
STIKSUM
EGGSUM
XRAYSUM
REARSUM
TREESUM
SUMMARY ROUTINES
TO DATA BANK

Figure 32. The arthropod data capture system.

storage media--Another problem which seems to create a considerable time-lag between the time when observations are made in the field and the time when "data analysis" and "report writing" can be done, is the data entry system used for all observations made by non-electronic methods. "Field" in this context refers to any location out-of-doors, although the same comparisons which are made also apply to non-electronically collected laboratory data.

Figure 33 shows four possible different data entry systems. From left to right, each system requires less time between initial observations as input, and "data analysis" as output, provided that the problem discussed in the previous section is solved. Most of the collected data in the SBNF currently pass through system #1. At least one study in the U. S. Forest Service (Byler, Hart, and Wood, 1975) uses system #2. Systems #3 and 4 would cut down the time-lag tremendously but require (1) an extra piece of hardware not currently available in this project, and (2) carefully trained and screened field technicians, especially for system #4. The latter system, in fact, is not known to be used yet in any environmental research program. The field-unit on which data are entered is a portable, handheld microprocessor-equipped terminal, with solid state memory packs capable of storing 8000 characters at one time. It looks similar to an ordinary handheld calculator. This data entry device is coming into greater use for commercial inventory purposes in stores and appears equally suitable, with minor modifications, for forest, insect, and other environmental inventories. Technical documentation on the device can be found in the June, 1976 issue of Datamation (Anonymous, 1976). The sensor on the device can "read" item identification information from bar code labels designed in the Universal Product Code, so it seems possible that trees and other fixed sites for environmental research could be tagged with bar code labels for ease of field data recording on-site. After returning from the field, one could immediately connect the memory pack to a computer via telephone and modem in order to list the data for investigator's verification purposes and other computerized processing which he/she may wish to perform.

Figure 33. Alternative Field Data Entry System


(1)
(2)
(3)
(4)
Location
In Field
In Office
On Computer
Comparisons
Common to all systems
Make Observation
Print data on field data forms
Keypunch cards
Read punched cards into data files
Make Observation
Print data on field data forms
Retype on O.C.R. forms
Read O.C.R. forms into data files
Make Observation
Print data on field data forms
Retype through off-line terminal onto mag tape casette
Feed local tape casette on-line over phone
Make Observation
Type on protable data entry microprocessor with mag tape casette (pocket size)
Feed Loçal tape casette on-line over phone
Store on Mag Tape
Verification & Correction
Data Analysis
Model Development
Report Writing

	(1)	(2)	(3)	(4)
Example of Use	EPA/SBNF Project	USFS Pest Damage Inventory, Byler, Hart and Wood, 1975	Modified form used to enter S.B. Co. Flood Control Data by Simulat. Modeling subproject	INNOVATIVE FUTURE? Presently used in supermarkets
Benefits compared to previous methods	———	Instead of punching cards, special forms are retyped may not save much manpower, but saves paper.	No need to punch or retype data onto paper media.	No need to print data on field forms & no need to have personnel sit at keypunch or terminal for long periods prior to data entry.

TREE POPULATION DYNAMICS SUBSYSTEM

Introduction

The vegetation subsystem is focused on (1) plant communities within the mixed conifer forest type in the San Bernardino Mountains and (2) the impact of oxidant air pollution on successional changes in these communities. Initially, it was necessary to characterize these communities and develop an understanding of their natural successional tendencies.

Research Objectives

Specific objectives of the Vegetation Sub-Committee were as follows:

1) To summarize field data collected in the past two years concerning vegetation of the San Bernardino Mountains. This summary will provide the following information for the field plots used in the study:

    a) Tree layer species
        1. Basal Area
        2. Percent composition
        3. Map of location
        4. Age distribution

    b) Shrub layer species
        1. Percent cover
        2. Frequency
        3. Percent composition
        4. Density

    c) Herbaceous species
        1. Level of importance
        2. Density
        3. Cover
        4. Frequency

2) To summarize field data concerning forest succession following fire in the San Bernardino Mountains. This summary will identity specific additional data, in terms of both forest type and decade of fire needed to complete the fire succession study.

3) To establish a series of plots, in a zone of high oxidant concentration, in order to observe the relationship between topography and tree mortality. Observation of mortality will be made on the plots in 1978.

Literature Review

Variation in forest composition in the San Bernardino Mountains has been discussed by Horton (1960) and Minnich et al. (1969). Their work was reviewed by Miller and McBride (1973) in the light of this project's overall objectives. The review concluded that a more detailed analysis of the vegetation was necessary to initially understand its characteristics and air pollution damage (McBride, 1973).

Forest succession in the San Bernardino Mountains had not been reported on prior to this project. A general review of the important variables in forest succession and the anticipated successional patterns in the study area was presented in the Task B report (Miller and McBride, 1973). Many of these conclusions concerning succession following fire were based on the observations Biswell (1967) and Weaver (1964) made in other parts of California and the West. Their work indicates a succession toward more tolerant species such as White Fir and Incense Cedar in the absence of fire. Fire plays a significant role in renewing pine through seedbed preparation, and furthermore, often eliminates competing species. The importance of fire to stand structure on 6 of the permanent plots was discussed by McBride (1973); on four of these plots, the age structure of ponderosa pine and Jeffrey pine can be explained on the basis of wildfire which occurred in the nineteenth century.

Materials and Methods

Field Sampling Technique--

Eighteen permanent plots were established in 1972 and 1973 to study air pollution injury to coniferous forest species in the San Bernardino Mountains. Plots were selected on the basis of relativity homogeneity of tree cover and the presence of 50 *Pinus ponderosa* or *P. jeffreyi* trees over 10 cm DBH (Fig.34). (Taylor, Task C Report, 1973).

Eighty-three temporary plots were established in 1974 to investigate forest condition as a function of time since the most recent fire. Fire-scarred trees were selected during a field reconnaissance on the basis of their occurrence in areas known to have burned at various times in the past. The fire history of the area was based on the work of Miller and McBride (1973). Each tree selected was sampled to determine the date of the most recent fire of sufficient intensity to scar the tree. A new method, involving cutting a thin wooden segment from the tree, was developed for this sampling (McBride and Laven, 1976). Plots (10m x 30m) were then established around a subsample of the selected trees to provide a chronological sequence of plots based on years since the most recent fire (Fig.34).

Twenty-two permanent plots were established in 1973 in a zone of high concentration of oxidant pollutants near Blue Jay, California. The plots were located according to aspect and topographic position as follows:

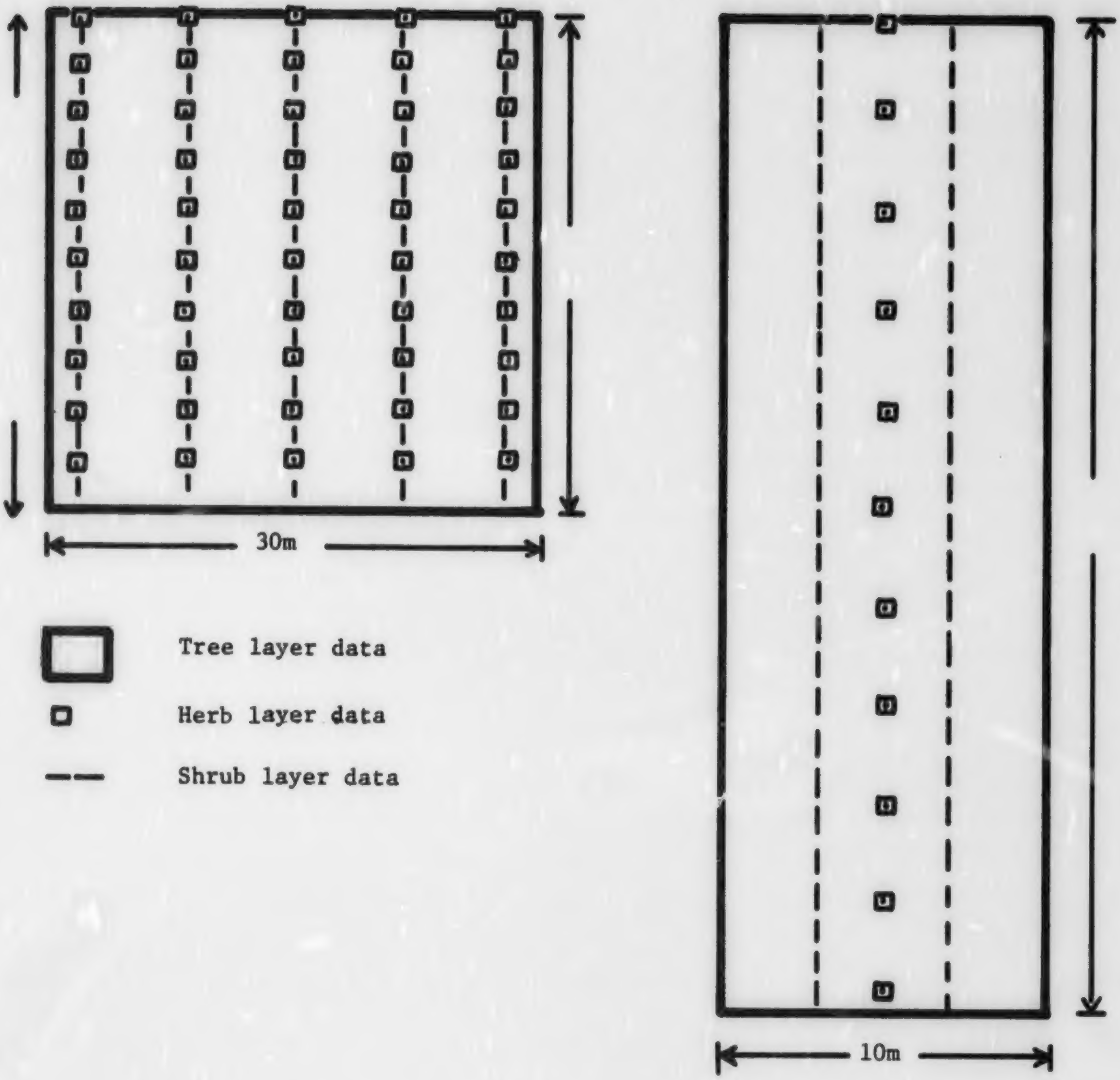

30m
10m
Tree layer data
Herb layer data
Shrub layer data

Figure 34. Layout of sampling locations on a 30 m section of a permanent plot and a plot used to study forest succession following fire.

Aspect	Topographic position	Number of plots
N	Slope	7
NE	Slope	4
NW	Slope	4
S	Slope	2
--	Ridge top	2
--	Drainage bottom	4

Each plot was 20 x 100 m and was oriented with the long axis parallel to the contour.

Characteristics of the tree layer and herb layer vegetation were sampled on the 18 permanent plots and 83 temporary plots by using the quadrat method (Clements, 1905). Only tree layer species were sampled on the 22 plots established to study the relationship between topography and tree mortality. The entire plot served as the quadrat for measuring the characteristics of the tree layer. Quadrats measuring 0.1 x 0.1 m were used to sample herb layer vegetation. These were established along five lines parallel to the long axis of the plot and 7.5 m apart. The herb layer subplots were located at intervals of 3 m along each of the five lines. Only 10 such herb layer plots were used to sample the plots established to investigate forest condition as a function of time since the last fire.

Characteristics of shrub layer vegetation were sampled using the line-intercept method (Canfield, 1941). Five lines running parallel to the long axis of the plot were used to sample the 18 permanent plots, and two lines were used to sample the 83 plots established to investigate forest conditions as a function of time since the last fire. The locations of these lines as well as of herb plots on the two types of plots is shown in Figure

Laboratory Analysis Procedures--

Field data of tree layer, shrub layer, and herb layer vegetation were to be summarized to provide levels of importance (Curtis and McIntosh, 1951) using a computer program developed by McBride and Stone (1976). Problems with access to the data at Livermore prevented the use of this program and as a result, tree layer and shrub layer data were summarized with hand calculators. No numerical summary of herb layer data was undertaken; however, species lists were prepared.

The cover data produced from this summary were compared by plotting change in cover over time (Hanes, 1971). Age distribution data were plotted using the methods developed by McBride (1974) and analyzed for curve type using the approach of Meyer and Stevenson (1943).

Dating of fire scars was accomplished by using a 10-power dissecting microscope to count annual rings between fire scars.

Results and Discussion

Summary of Field Data on Vegetation--

Field data collected previously was summarized for tree layers on each of the 18 permanent plots. An example of this data which shows basal area, percent composition, and tree density is given in Table 11. Tree location maps showing tree number, dbh, and 1973 smog injury score were also prepared, and were drawn for 30 x 30 m segments of each transect (Fig. 35). Age distribution tables were prepared for each of the 18 permanent plots and the age distribution curves drawn (Table 12; Fig. 36).

The percentage species composition of each of the 22 plots established to study the relationship between topography and tree mortality in a zone of high concentration of oxidant pollutants is shown in Table 13. This data indicates that a higher percentage of ponderosa pine occurs on south facing slopes and ridge top positions. North facing slopes and drainage bottoms exhibit a higher percentage of white fir. The diameter class distribution of trees according to topographic position and slope is shown in Table 14. Smaller diameter classes of ponderosa pine and white fir were well represented on northerly facing slopes and ridgetops. Smaller diameter incense cedar were common in the drainages, while the south facing slopes exhibited few smaller diameter trees. This presence of smaller size classes may reflect the general capacity for various species to become established on different physiographic sites.

Shrub layer data were summarized to present information on percent cover, frequency, percent composition, and density on each of the 18 permanent plots (Table 11).

A list of herbaceous species on each plot and a summary list (McBride et al., 1975) for the Montane forest zone in the San Bernardino Mountains were prepared. Table 11 illustrated the type of data summary which will be available for herbaceous data once access to the data banking system is established.

Complete data summaries of tree layer and shrub layer vegetation, as well as herb layer species lists, are available from the Department of Forestry and Conservation, University of California, Berkeley, CA 94720.

Observations at the forest community level--A review of the summarized data suggests that the two general coniferous forest types defined by Horton (1960) -- Pine Forest and Ponderosa Pine-White Fir Forest -- should be further subdivided into five types as follows: Ponderosa Pine Forest; Ponderosa Pine-White Fir Forest; Ponderosa Pine-Jeffrey Pine Forest; Jeffrey Pine-White Fir Forest. A description of typical examples of each of these types was presented above in the "Description of Subsystem Properties and Processes."

Future work in modeling the impact of oxidant air pollutants on the forest must consider the variation in forest types identified by this study. The breakdown used previously between ponderosa and Jeffrey pine types may not be adequate if we are to understand the impact of air

TABLE 11. VEGETATION DATA FOR THE U.C. CONFERENCE GROUND PLOT.

Tree layer:

Species	No. of trees[*]	% Species composition[+]	Density[‡]	Basal area[§]
Pinus ponderosa	65	83	309.5	44.76
Quercus kelloggii	13	16	61.9	1.08

Shrub layer:

Species	% Frequency	Density/100 m	% Cover
Arctostaphylos pringlei	40	0.57	1.24

Herb layer:

Species	Relative frequency %	Relative density %	Relative dominance %	I.V.
Bloomeria crocea	3	1	2	6
Bromus carinatus	9	4	5	18
Bromus tectorum	9	42	14	65
Convulvulus fulcratus	9	6	15	30
Corethrogyne filaginifolia var. brevicula	8	7	10	25
Cryptantha simulans	6	2	1	9
Elymus glaucus	3	1	1	5
Erigeron foliosus	4	1	4	9
Gayophytum nuttallii	1	1	1	3
Gnaphalium chilense	1	2	3	6
Iris hartwegii var. australis	24	8	25	57
Koeleria cristata	8	3	4	15
Lathyrus laetiflorus	1	0	3	4
Linanthus breviculus	8	17	5	30
Lotus argophyllus var. decorus	3	1	2	6
Monardella linoides spp. stricta	1	3	1	5
Sitanion hystrix	3	1	3	7
Vicia californica	1	0	1	2

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[*] Number of trees on the plot over 10 cm dbh.

[+] Percent species composition on the basis of number of trees.

[‡] Number of trees/a

[§] Basal area in m^2/ha

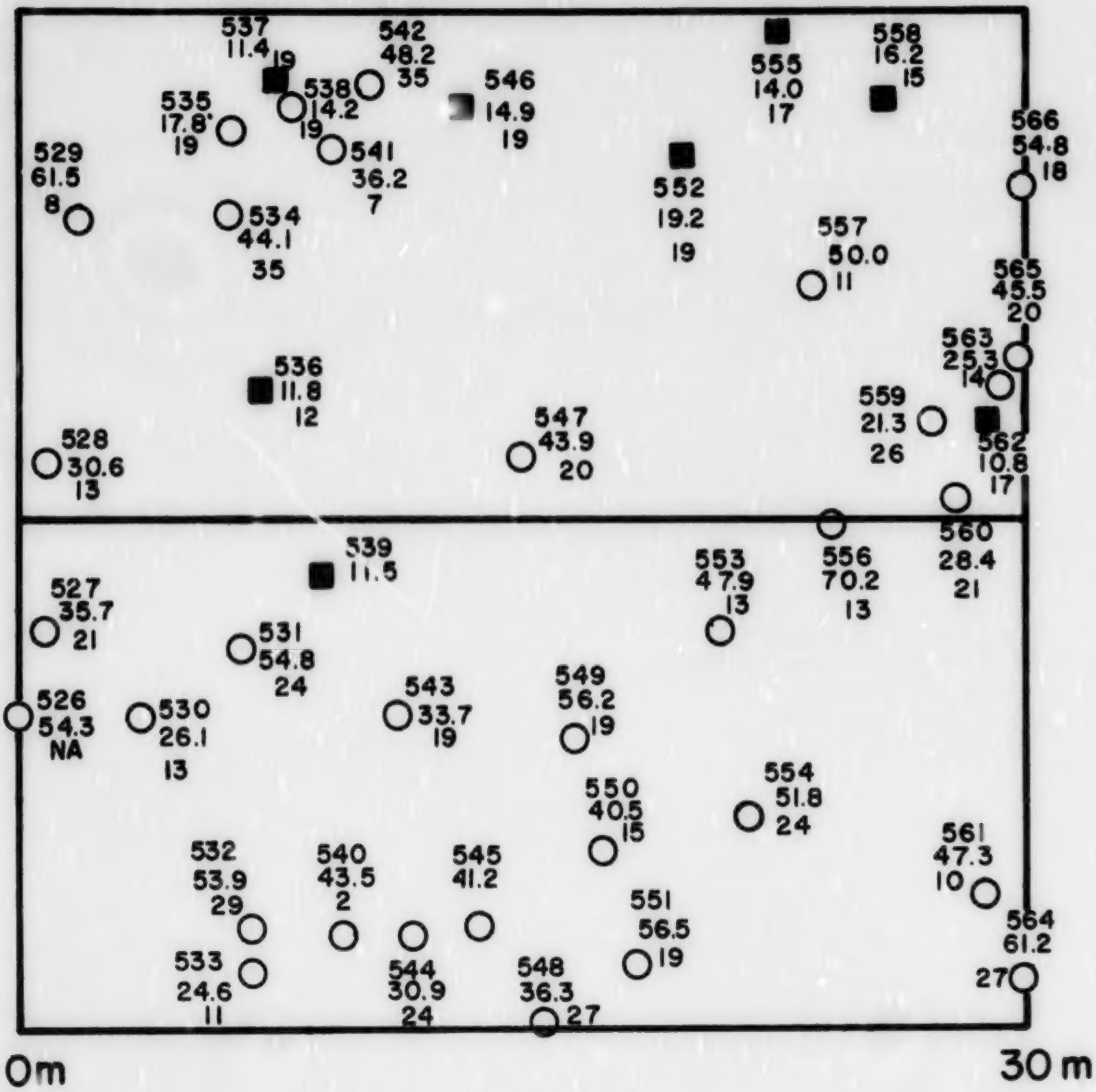
537 11.4 19
542 48.2 35
538 14.2 19
535 17.8 19
546 14.9 19
555 14.0 17
558 16.2 15
529 61.5 8
541 36.2 7
552 19.2 19
566 54.8 18
534 44.1 35
557 50.0 11
565 45.5 20
563 25.3 14
536 11.8 12
559 21.3 26
547 43.9 20
562 10.8 17
528 30.6 13
560 28.4 21
539 11.5
553 47.9 13
556 70.2 13
527 35.7 21
531 54.8 24
526 54.3 NA
530 26.1 13
543 33.7 19
549 56.2 19
550 40.5 15
554 51.8 24
532 53.9 29
540 43.5 2
545 41.2
561 47.3 10
551 56.5 19
564 61.2 27
533 24.6 11
544 30.9 24
548 36.3 27
0m
30 m

Figure 35. Plot map of 0-30 m section of U.C. Conference ground plot.

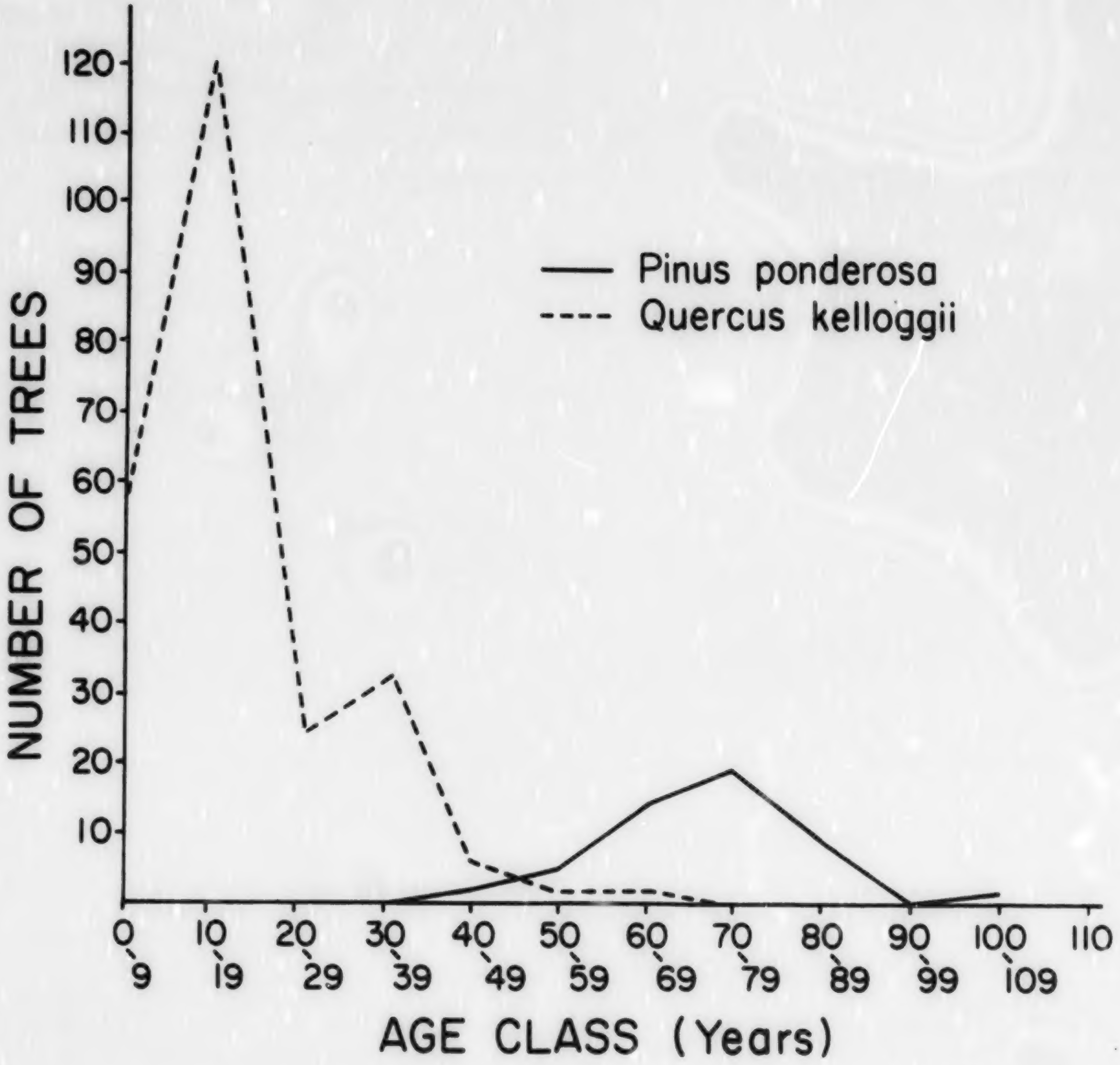

Figure 36. Stand age distribution curve for U.C. Conference ground plot.

TABLE 12. STAND AGE DISTRIBUTION FOR THE U.C. CONFERENCE GROUND PLOT.

	Number of individual trees	
Age class (yr)	Pinus ponderosa	Quercus kelloggii
0 - 9	0	57
10 - 19	0	121
20 - 29	0	25
30 - 39	0	32
40 - 49	2	8
50 - 59	7	8
60 - 69	14	2
70 - 79	19	2
80 - 89	10	0
90 - 99	0	0
100 - 109	2	0

pollution over these mountains.

A summary of tree, shrub, and herb layer data leads to the identification of three species not previously reported for the San Bernardino mountains. This type of information is valued by taxonomists and plant ecologists concerned with the distribution of plant species.

A review of stand age distribution data suggests four general patterns of age structure significant to future successional changes on the 18 permanent plots. In order of increasing occurrence, these patterns are as follows:

1. No significant regeneration over the last 20 years;
2. Regeneration of pine,
3. Regeneration of more tolerant conifers;
4. Invasion by Black oak.

The occurrence of any particular pattern is independent of the gradient

TABLE 13. PERCENTAGE SPECIES COMPOSITION ON PLOTS ESTABLISHED TO STUDY THE RELATIONSHIP BETWEEN TOPOGRAPHY AND TREE MORTALITY IN A ZONE OF HIGH CONCENTRATION OF OXIDANT POLLUTANTS.

	Species						
Plot name	Ponderosa pine	White fire	Incense cedar	Sugar pine	Black oak	Dog-wood	Other species
	% of total no. of trees per plot						
North plot							
1N	26	34	9.4	9.4	21	--	--
6N	27	39	13	8.1	13	--	--
2N	15	73	0.69	0.69	9.1	0.69	0.69
4N	11	74	5.3	11	--	--	--
5N	29	38	9.5	9.5	9.5	4.8	--
19N	7.8	50	11	13	19	--	--
20N	26	24	--	24	26	--	--
Percent of total	26	24	7.0	11	16	2.7	0.69
Ridge plots							
17R	66	1.9	23	3.8	1.9	--	3.8
18R	52	14	9.1	5.7	6.8	--	--
Percent of total	49	14	16	4.8	4.4	--	3.8
Northwest plots							
9NW	43	15	1.5	3.0	37	--	--
10NW	30	31	23	11	5	--	--
11NW	47	2.2	42	2.2	5.5	--	1.1
12NW	27	44	21	1.4	6.8	--	--
Percent of total	37	23	22	4.4	1.4	--	1.1

TABLE 13. CONTINUED.

Plot name	Species						
	Ponderosa pine	White fir	Incense cedar	Sugar pine	Black oak	Dog-wood	Other species
	% of total no. of trees per plot						
Northeast plots							
13NE	--	--	--	--	--	--	--
14NE	11	39	13	24	11	2.6	--
15NE	32	32	23	8.5	3.8	0.9	--
16NE	32	35	21	1.3	9.3	1.3	--
Percent of total	25	35	19	11	8.0	1.6	--
Drainage plots							
3D	29	21	31	--	10	--	8.6
4D	5.8	30	10	5.8	28	20	--
7D	35	43	2.5	7.5	12.5	--	--
8D	5.2	6.2	73	--	4.1	10	1.0
Percent of total	19	25	29	6.7	13.7	15	4.8
South plots							
21S	56	--	12	--	32	--	--
22S	50	--	42	--	8.3	--	--
Percent of total	53	--	27	--	20	--	--

TABLE 14. MEAN NUMBERS FOR EACH SIZE CLASS OF 5 SPECIES IN THE 22 ASPECT PLOTS.

Diameter class (cm)	Ponderosa pine	White fir	Incense cedar	Sugar pine	Black oak
Ridge-top plots (2)					
10.0 - 29.9	15 ± 1.96*	22 ± 0	8 ± 0	2 ±1.9	5 ±0
30.0 - 59.9	17.5± 0.98	0	3 ± 0	1 ±0	1 ±0
60.0 - 89.9	8 ± 7.84	1 ± 0	3 ± 0	1 ±0	0
90.0 +	0	1 ± 0	0	0	1 ±0
South facing plots (2)					
10.0 - 29.9	4.0± 0	0	1.5± 0.9	0	1.0±0
30.0 - 59.9	6.5± 8.8	0	2.0± 1.9	0	3.5±4.9
60.0 - 89.9	4.0± 0.0	0	1.0± 0	0	4.0±0
90.0 +	0	0	0	0	0
Northwest facing plots (4)					
10.0 - 29.9	21 ±15.4	16.8 ±23.7	20.3±12.9	3.7±6.1	7.5±2.0
30.0 - 59.9	6 ± 3.4	1.75± 2.5	1.0± 0	1.5±1.0	1.5±1.4
60.0 - 89.9	1.5± 1.0	0	1.7± 1.8	1.0±0	1.3±0.9
90.0 +	1.3± 0.9	1 ± 0	1.0± 0	1.0±0	0
Northeast facing plots (4)					
10.0 - 29.9	14.7±18.4	19 ±19.4	8.3± 9.1	2.7±4.6	3.5±2.9
30.0 - 59.9	6.5± 2.9	1.7 ± 0.9	4.3± 4.0	3.0±3.9	1.5±0.9
60.0 - 89.9	2 ± 0	6 ± 0	2.5± 2.9	1.5±1.0	0
90.0 +	1 ± 0	1 ± 0	1 ± 0	0	1 ±0
North facing plots (7)					
10.0 - 29.9	5.7± 8.6	28.4 ±53	3.7± 6.1	2.3±3.6	7.1±6.9
30.0 - 59.9	2.6± 2.1	5.0 ± 6.4	1.7± 1.9	2.8±1.9	1.0±
60.0 - 89.9	2.5± 1.9	1.8 ± 1.6	2.0± 1.6	1.0±0	1.5±1.0
90.0 +	1.6± 1.6	1.3 ± 0.9	1.0± 0	0	1.0±0

TABLE 14. CONTINUED.

Diameter class (cm)	Ponderosa pine	White fir	Incense cedar	Sugar pine	Black oak
		Drainage or swale plots (4)			
10.0 - 29.9	1 ±0	8.5±10.1	16 ±33	3 ±0	7.3±10.7
30.0 - 59.9	3.5±4.0	3.8± 6.1	9.3±16	1.5±1	3.0± 3.9
60.0 - 89.9	10.5±6.9	1.8± 1.6	5 ± 6.5	1 ±0	1.3± 0.9
90.0 +	1.5±1.7	1.5± 1	1 ± 0	0	0

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*95 percent confidence limits

of air pollution over the forest. The 18 plots, however, represent an inadequate sample to establish the relationship between air pollution injury and successional change.

Summary of Field Data Concerning Forest Succession Following Fire--

Data collected during the previous field season (1974) in a study of forest succession following fire was summarized during 1975-76. An example of vegetation data is shown in Table 15, and a typical stand age analysis curve is shown in Figure 37.

In the analysis of this data, the frequencies of wildfires in the San Bernardino mountains were shown to be as follows: before 1905, the intervals between fires for ponderosa pine and Jeffrey pine were 10 and 12 years, respectively; after 1905, the intervals were 22 and 29 years, respectively. The significant change after 1905 is due to an increase in fire control methods in the San Bernardino mountains which occurred as a result of state and federal legislation in that year.

Evaluation of fire plot data indicated the necessity of a new approach to our study of succession following fire. Close examination of wood specimens showing fire scars indicated quite different units of the mosaic of forest stands. Recognition of the scope of this variation dictates that future work on fire succession focus on a limited number of physiographic sites within one forest type. The overall approach originally proposed now appears unmanageable because of the enormous sample size required. As a result of this data summary, the study of forest succession following fire has been redirected to identify various physiographic units within the montane forest zone of the San Bernardino mountains and to establish successional patterns following fire for each of these units. This will provide baseline data which must be understood about forest succession before the impact of oxidant air pollutants on succession can be predicted.

TABLE 15. VEGETATION DATA ON FIRE PLOT P-38.

Tree layer:

Species	No. of trees[*]	% Species composition[+]	Density[‡]	Basal area
Pinus ponderosa	5	38	1665	298.7
Quercus kelloggii	8	62	3330	76.3

Shrub layer:

Species	% Frequency	Density/100 m	% Cover
Arctostaphylos pringlei	50	3.3	1.85
Ceanothus cordulatus	100	10.0	13.08

Herb layer:

Species	Relative frequency (%)	Relative density (%)	Relative dominance (%)	I.V.
Cryptantha simulans	50	50	36	136
Iris hartweigii var. australis	25	44	36	105
Poa fenderliana	25	6	28	59

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[*] Number of trees on the plot over 10 cm dbh.

[+] Percent species composition on the basis of number of trees.

[‡] Number of trees/ha.

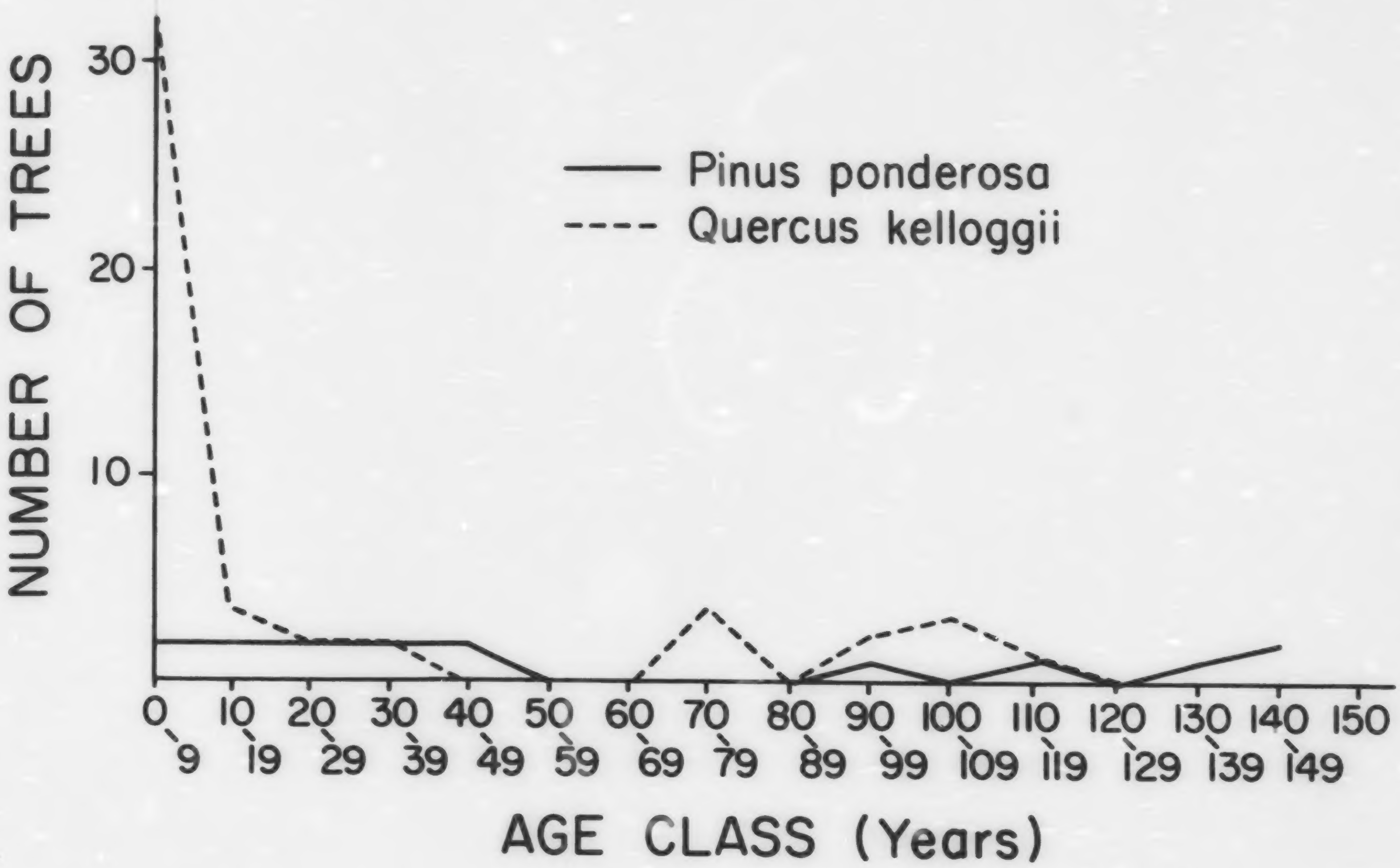

Figure 37. Stand age distribution curves for fire plot P-38.

·OXIDANT FLUX-CANOPY RESPONSE SUBSYSTEM

Introduction

Pollutant Doses/Vegetation Injury Response--

Chronic injury to vegetation in the San Bernardino Mountains is being inflicted upon a complex mosaic of forest types which exist along gradients of increasing elevation and decreasing rainfall in a west-to-east direction. Oxidant air pollutants at adverse concentrations and durations also decrease from west to east. Differences in such common environmental variables as soil-moisture availability, air temperature, relative humidity, and wind have an important influence on degree of plant sensitivity to oxidant pollutants. An integral part of this task is to gain an understanding of the importance of other environmental variables in influencing plant sensitivity; the role of other stresses acting in concert with chronic oxidant injury to cause mortality is also of special interest.

Ozone is of particular interest because it is primarily responsible for injury to conifers. Needle symptoms observed under natural conditions can be duplicated by fumigation with ozone (Miller et al., 1963). The role of other oxidants, e.g., PAN and NO_2, may assume more importance with broadleaf trees, shrubs, and with herbaceous understory plants. Injurious effects from NO_2 are probably negligible.

Research Objectives

Two time scales are useful in describing oxidant dose/tree injury responses, namely, the within season effects on foliage and the accumulated effect of injury in consecutive years. The measurement of injury to selected species is based primarily on visual description for the within-season interval and only partially on visual description of needle and tree crown characteristics for the consecutive year time scale. In the latter scale, measurements of diameter and height growth are also helpful. Growth effects are described in the "Stand Tree-Growth Subsystem" section of this report. The specific objectives of this section are to:

1) Record the occurrence of injury to ponderosa pine needles at intervals during the growing season.

2) Record the amount of injury to all tree species in the 18 vegetation plots at the end of each growing season in terms of an injury score, and record mortality rates.

3) Compare the doses of oxidant recorded at monitoring stations near the 18 vegetation plots. Injury to ponderosa and Jeffrey pines and black oak in order to obtain a firest approximation of

the within-season dose response.

4) Recognize oxidant injury symptoms on shrub and herb layer species.

Materials and Methods

Scoring Oxidant Injury to Needles and Whole Tree Crowns--

Two injury rating systems have been employed to provide an index of the amount of oxidant injury. The first system is employed with container-grown seedlings and with saplings less than 10 cm dbh, where the trees are usually small enough so that needle complements can be reached and inspected from the ground. Needles are inspected closely to determine the amount of chlorotic mottle, necrosis, and abscission (Fig. 38). Each of the three symptoms are rated as: none = 0, very slight = 1, slight = 2, moderate = 3, and severe = 4. The worst possible score for a single needle complement is 12 and comparisons of complements of the same age from tree to tree form the basis for evaluation of injury differences. Following chronic injury, the current year and one-year-old needle complements are the only ones remaining. With the seedling-sapling injury evaluation, the higher scores mean greater injury.

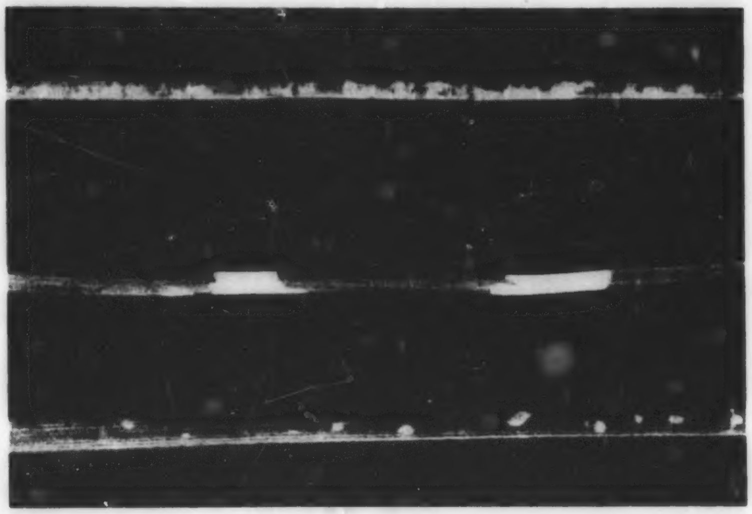

Figure 38. Chlorotic mottle (top), necrosis caused by an experimental ozone fumigation (middle), and superficial necrotic flecks not associated with oxidant injury but rather winter weather (lower).

The second system is employed for whole crowns of ponderosa and Jeffrey pines 10 cm dbh and larger in the field. It was originally contrived as a "penalty score or index" system useful to forest managers in marking trees for removal during sanitation salvage. Most of the elements making up this score must be determined by binocular inspection of each tree. With this system, the higher scores mean less injury for both pines (Miller, 1973) and associated species (Taylor, 1974). Black oak is examined in late August and conifer observations begin in mid-September each year.

From 1968 to 1973, three nearby groups of 10 ponderosa pine saplings averaging 18 years of age were subjected to different treatments: (1) activated charcoal-filtered air in a greenhouse, (2) unfiltered ambient air polluted with oxidants in a second greenhouse, and (3) polluted ambient air outside of the greenhouses. The abbreviations FAH, AAH, and AAO represent each treatment in the order named above. The differences in growth, needle biomass retained, and needle injury symptoms among these three treatments are described in the "Oxidant Effects on Tree Growth" section.

The AAO treatment in this experiment offered the opportunity to observe the rate of symptom development on current and one-year-old needles in relation to total oxidant dose. In addition, the rate of current year needle growth (cm) was measured (40 needles per tree monthly) to determine (1) the relationships of season to inception and completion of needle elongation; (2) the time of appearance and intensity of needle symptoms; and (3) the accumulated oxidant dose associated with needle injury.

Results and Discussion

Injury to Foliage of Ponderosa Pine Saplings in Ambient Polluted Air During Three Seasons--

In Figure 39, the data for three years, 1969, 1970, and 1971, with complete records are combined. Trees growing outside greenhouses began to show slight injury to current year needles before needle elongation was completed (between Julian days 200-225, July 19 to August 13). Injury continued to increase on current year needles for the duration of the summer observation period.

In Figure 39 (left), an average of the three years shows that by Julian day 250 (September 7), the current year needles has a score of 2.2, indicating slight chlorotic mottle; there was usually no necrosis and almost always no abscission of current year needles. On the same date, the combined score of the current and one-year-old needles was about 9, suggesting a combination of mottle, necrosis, and abscission scores for one-year-old needles totaling about 7, with current year needles having a score of about 2. The worst score a single needle complement could have is 12. Two-year-old needle complements were rarely present on this group of injured saplings because the abscission of older needles is the most characteristic result of chronic injury. The trees in the filtered air house nearby usually retained at least 4 needle complements.

The accumulated oxidant dose ($\mu g/m^3$-hr) since June 1, which is associated with the current year, or one-year-old needle injury expressed in Figure 39 (left), can be estimated by transferring the injury score to Figure 39 (right). For example, the current year needle score of 2.2

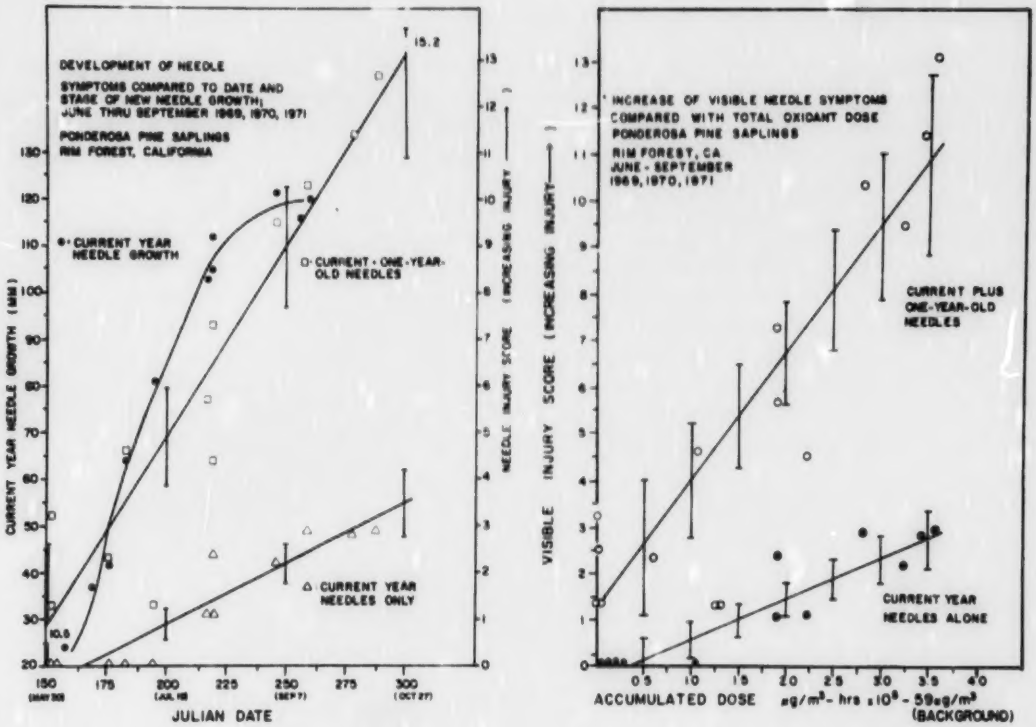

Figure 39. Development of oxidant injury symptoms on current, and current plus one-year-old, needles of ponderosa pine saplings, in relation to stage of current year needle growth and time during the summer season (left) and in relation to total dose of oxidant (right). (For approximate absolute values, oxidant dose might be multiplied by 0.8 to comply with a new, oxidant calibration standard.)

on September 7 is associated with a dose of 2.75 X 10^5 µg/m^3-hrs total oxidant. The 95% confidence limits indicated in both parts of Figure may not encompass all of the variation because they assume that 100% of the air monitoring data were available; on the average, about 90% was available.

Other precautions must be introduced when interpreting the dose response in Figure 39. The frequency of pollution episodes is random so the accumulated dose is a composite of high, moderate, and low dose days. The relative injury-inducing effect of different dose sequences and associated weather conditions is unknown. The three years of data which comprise Figure 39 are not sufficient to sample the variation involved. It is also assumed that visible injury increases by equal intervals or units from the first visible symptoms to the most severe.

Another example of the usefulness of injury to current year needles or broad leaves as an indicator of dose response is shown (Table 16) for pines and black oaks (for all plots in which oaks are present) during 1974 and 1975. At Barton Flats, Sky Forest, and Camp Paivika, the 1975 dose (June-October) was 65, 68, and 67%, respectively, which was as great as in 1974. The injury to current year needles of pines in all plots was also less--56% of that observed in 1974. Injury to oaks was about the same in both years. Climatic influences are not considered here. Further investigations will determine the true form of the dose-injury curve for current year foliage. These investigations must also evaluate the controlling influences of soil moisture availability, plant water stress, and other important microclimatic variables on the development of injury. The steps which have been taken to understand environmental interactions are described in the "Stand Moisture Dynamics and Microclimate Subsystem" section.

Injury to Major Overstory Species Along a Gradient of Decreasing Oxidant Dose--

Identification of the oxidant gradient with monitoring station comparisons in 1974 and 1975--A regression of all hourly oxidant averages at Sky Forest against corresponding hourly averages at each of 10 other stations in 1975, as located in Figure 1, has provided a very useful index to compare the seasonal doses. In Table 17 stations are listed in order of decreasing dose according to their regression coefficients; the corresponding correlation coefficients are not lower than 0.83, lending good confidence to these paired comparisons.

The order of listing of the stations in Table 17 agrees quite well with the west-to-east or south-to-north sequence of increasing distance from the source as indicated in Figure 16. The most notable exception is Lake Gregory APCD which appears too low. It is most closely located to Camp Paivika which has the highest hourly average oxidant concentrations of all stations compared. The latter is located on a ridge heavily influenced by the upslope flow while Lake Gregory is screened from such direct flow by higher upwind terrain; this may account for some of the difference. Analysis of surface air flow in this area did show much lighter winds at Lake Gregory (see section: "General Description of Ecosystem Properties: Temporal and Spatial Trends of Oxidant Air Pollutant Concentrations").

In Table 18, five stations are compared with Sky Forest in consecutive years. Regression coefficients for 1974 and 1975 at Camp Paivika, Running Springs, and Snow Valley are quite close, but the comparisons between years at Barton Flats and Big Bear APCD are not as similar, however only the May through July period is compared at Big Bear in 1975.

Relative seasonal doses, mean injury score and mortality rates of ponderosa and Jeffrey pines at ten selected monitoring stations-vegetation plot paris--An approximation of the relationship between seasonal oxidant dose and the amount of chronic injury to overstory species at the end of the 1975 season is shown in Figure 40. The relative seasonal oxidant doses at ten stations are expressed as the regression coefficients from Table 16.

TABLE 16. COMPARISON OF OXIDANT INJURY TO PONDEROSA AND JEFFREY PINES AND BLACK OAK IN 1974 AND 1975.

	Total pines in each plot with chlorotic mottle on current year needles		Injury to leaves of black oak in early September[*]	
	Percent		Injury score	
Plot name	1974	1975	1974	1975
COO	68	28	5	5
BP	36	28	5	5
CP	36	40	5	5
SF	60	45	5	5
DWA	40	28	5	5
UCC	36	21	7	7
TUN2	38	28	7	6
DL	ND[+]	15	ND	5
GVC	16	0	7	6
BL	4	0	NP[‡]	NP
NEGV	0	0	NP	NP
SC	0	0	NP	NP
HV	0	0	8	8
SCR	87	33	6	5
CA	31	17	6	6
BF(PP)	30	24	8	7
BF(JP)	24	8	ND	ND
CAO	28	0	8	8
HB	1	0	NP	NP
SV1 + SV2	ND	ND	8	8
Means	30	17	6	6

*Score ranges from 8 (no injury) to 1 (severe injury)

[+] ND = no data

[‡] NP = oaks not present in the plot

TABLE 17. REGRESSION OF ALL MATCHING HOURLY AVERAGE OXIDANT CONCENTRATIONS AT PAIRED STATIONS IN 1975 USING SKY FOREST AS A BASELINE FOR COMPARING EACH OF TEN OTHER STATIONS.

Station compared with Sky Forest	Time period	Total hours	Regression coefficient	Correlation coefficient
Camp Paivika	May-Oct 1974	3744	1.058	0.911
University Conference Center	July-Oct 1975	2979	0.977	0.961
Camp Angeles	Aug-Oct 1975	1521	0.803	0.914
Barton Flats	May-Oct 1975	3749	0.720	0.897
Running Springs	May-Oct 1975	3258	0.701	0.940
Lake Gregory APCD	May-Aug 1975	2031	0.674	0.964
Rock Camp	July-Aug 1975	597	0.592	0.926
Snow Valley	May-Oct 1975	3615	0.578	0.894
Heart Bar	July-Oct 1975	1706	0.552	0.832
Big Bear APCD	May-July 1975	1971	0.296	0.884

TABLE 18. REGRESSION OF ALL MATCHING HOURLY AVERAGE OXIDANT CONCENTRATIONS DURING 1974 AND 1975 OF FIVE OXIDANT STATIONS EACH PAIRED WITH SKY FOREST.

Station comparison	Time period	Regression coefficient	Correlation coefficient
Sky Forest vs Camp Paivika	May-Oct 1974	1.028	0.944
	May-Oct 1975	1.058	0.911
Sky Forest vs Running Springs	May-Oct 1974	0.677	0.951
	May-Oct 1975	0.701	0.940
Sky Forest vs Snow Valley	May-Oct 1974	0.579	0.910
	May-Oct 1975	0.578	0.894
Sky Forest vs Barton Flats	May-Oct 1974	0.597	0.911
	May-Oct 1975	0.720	0.897
Sky Forest vs Big Bear APCD	May-Oct 1974	0.478	0.886
	May-July 1975	0.296	0.884

The longest record of seasonal oxidant (1968-1976) at Sky Forest and one of the longest records of ponderosa pine injury at the nearby Dogwood plot (see Miller, 1973) provide a baseline describing the worst case conditions to be expected. The procedure of matching the remaining nine regression numbers with the mean oxidant injury score of pines in the vegetation plot nearest each monitoring station provides a display of points helpful in understanding the dose requirement for different amounts of chronic injury. It is important to emphasize that Figure 40 does not deal with mathematical terms that would allow a best fit line to be added to these points which could then be used as a dose-response curve. Future work plans will include improved air monitoring data at each vegetation plot and improved, more quantitative, tree injury data. The solid triangles in Figure 40 show the accumulated mortality in these 10 selected plots between 1973 and 1975. The lower mortality in the higher dose regions may be related to a lower residual population of oxidant susceptible individuals. More complete mortality records are shown for all 18 plots in Tables 19a,b,c.

Observations of the end-of-season injury to ponderosa and Jeffrey pines and black oak in 1974 and seasonal dose shown with respect to topography--In September, October, and early November, 1974 all tree species at 18 major study sites or plots were scored individually by binocular inspection. The data from conifers could be obtained this late in the season; however, the single most important deciduous species, black oak, was also evaluated during 3 days (August 28-31) to distinguish between oxidant injury symptoms and natural autumn senescence of leaves.

The injury to black oak as of August 31, 1974, at several representative study sites, along with the June through August accumulated dose at nearby monitoring stations, is shown in relation to the topographic projection of the San Bernardino Mountains (Fig. 41). The darkened portion of the bar representing oak injury is for leaf chlorotic mottle and interveinal necrosis. A score of 8 means no injury. The remaining portion of the score is the sum of scores for leaf complement, leaf size, and twig mortality, not shown separately. These data suggest that oak shows no injury symptoms when the accumulated June through August dose does not exceed about 2.0 X 10^5 $\mu g/m^3$-hr, or in other words from around Snow Valley eastward. It is also interesting to note that a frost in late May killed all the emerging foliage east of a point midway between Camp O-ongo and Snow Valley. Frost damage increased with elevation. The frost-killed leaves were quickly replaced by new foliage; it is difficult to assess how this may influence subsequent levels of oxidant injury to oak.

The distribution of ponderosa and Jeffrey pines into various injury classes with respect to the distance of the study site along the gradient of oxidant dose (June through September) is illustrated above the topographic projection in Figure 42. It is important to realize that the 1974 distribution into injury classes is also a product of earlier years when the oxidant levels were not always as high as in 1974. The trend towards greater numbers in the "very slight" (29-35) category is quite evident in the eastern plots receiving lower doses, e.g., Holcomb Valley (HV).

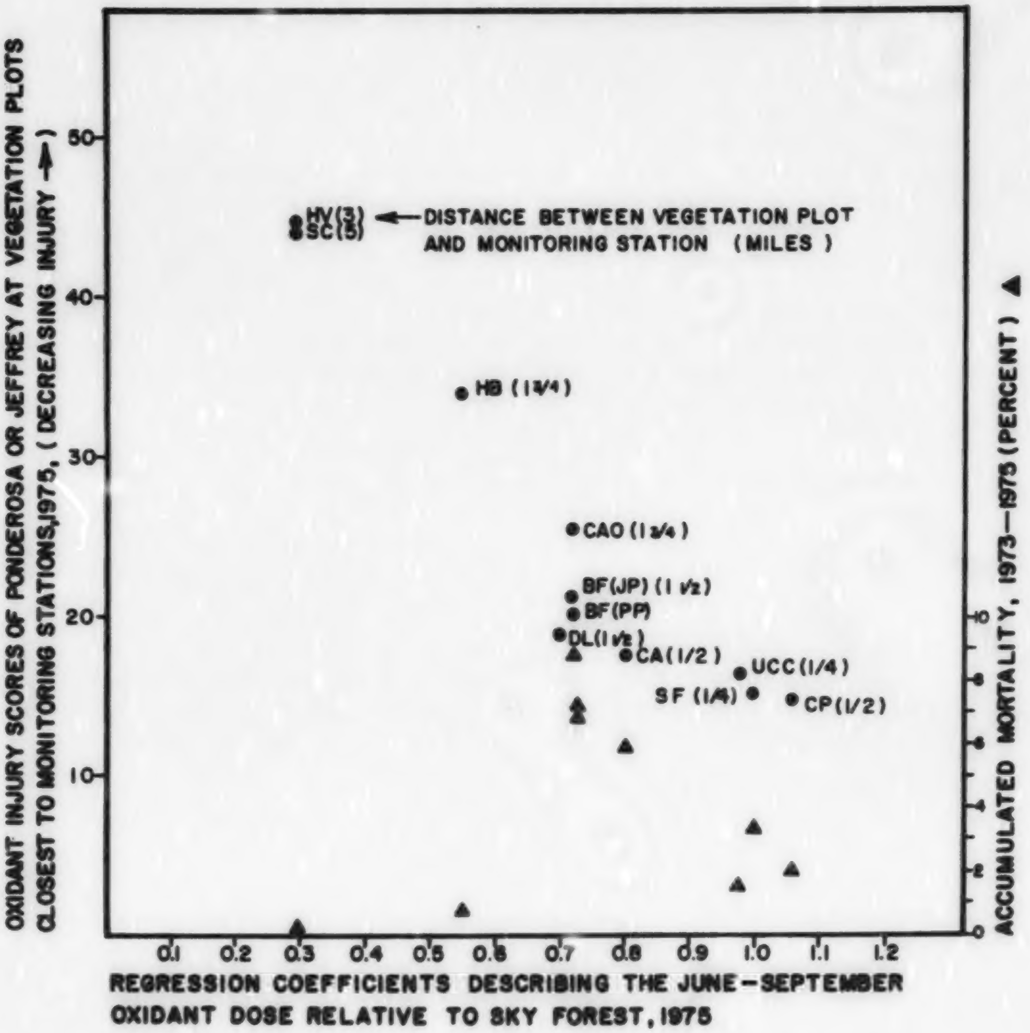

Figure 40. Relationship of oxidant doses at several monitoring stations expressed as a ratio of that received at Sky Forest with the average oxidant injury scores of ponderosa and Jeffrey pines at the plots nearest each station.

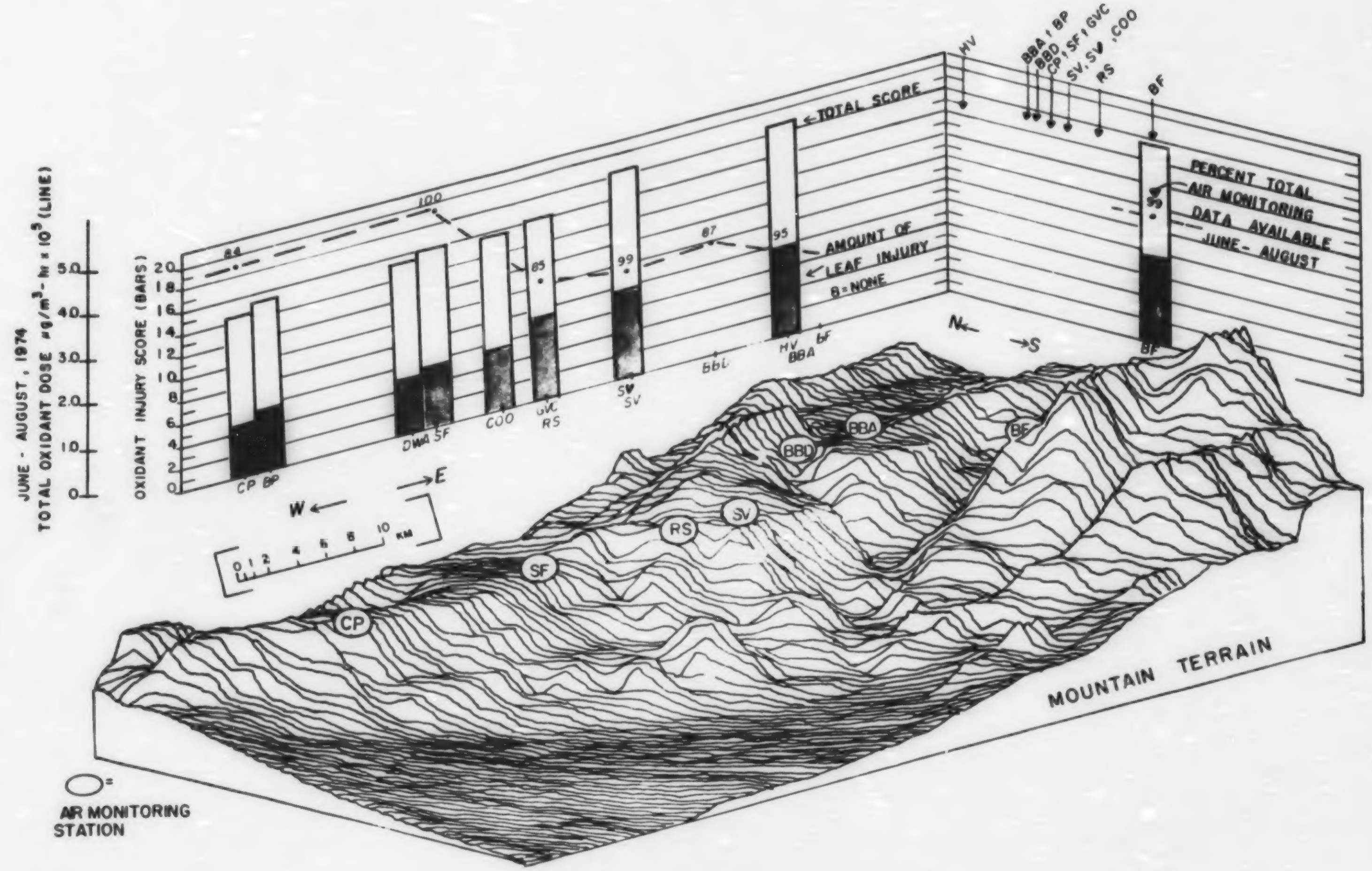

Figure 41. Topographic projection of the San Bernardino Mountains, showing a comparison of oxidant injury to black oaks at major study sites, August 31, 1974, with accumulated total oxidant dose, June-August, measured at nearby monitoring stations. (For absolute values, oxidant dose might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et al., 1976).

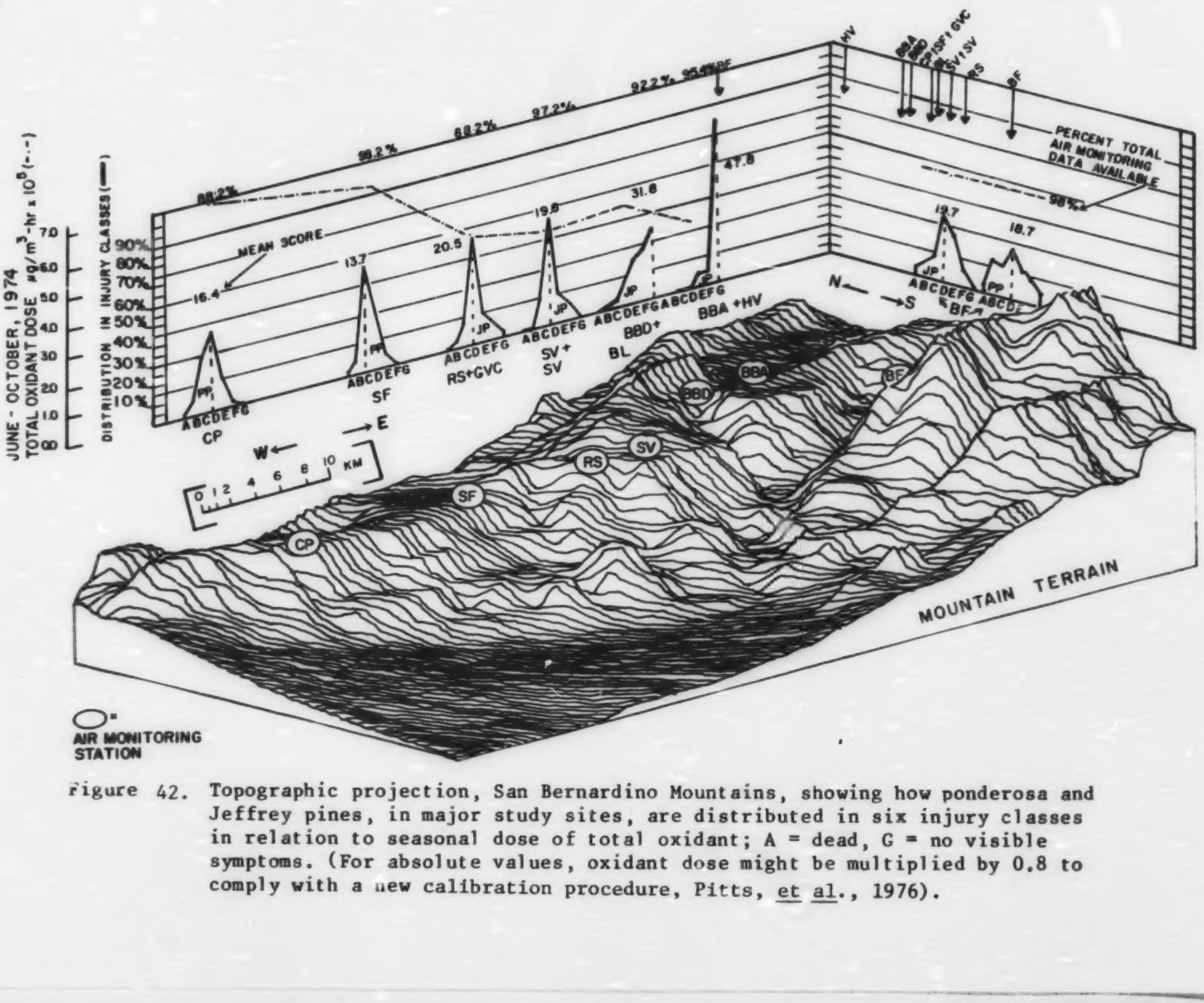

Figure 42. Topographic projection, San Bernardino Mountains, showing how ponderosa and Jeffrey pines, in major study sites, are distributed in six injury classes in relation to seasonal dose of total oxidant; A = dead, G = no visible symptoms. (For absolute values, oxidant dose might be multiplied by 0.8 to comply with a new calibration procedure, Pitts, et al., 1976).

The assumption has been made that ponderosa and Jeffrey pine respond similarly to oxidant stresses. Ponderosa pine is replaced by Jeffrey pine in the natural stands east of Camp O-ongo (COO) and at Barton Flats (BF). The validity of this assumption can be verified partially by examining the distributions of the two species where they intermix at Barton Flats (BF - Fig. 42). These data indicate reasonable similarity at a common site, but the influence of other environmental variables which change continuously along the oxidant gradient, e.g., soil moisture availability, air temperature, and humidity, must be examined more intensively to understand how they influence oxidant susceptibility over long term responses of trees.

The influences of topography on pollutant transport have been discussed elsewhere in this report. Figure 41 and 42 are helpful in forming a conceptualization of the interrelationships between distance from pollutant source, seasonal oxidant dose and the accumulated chronic injury to overstory vegetation.

Trends in oxidant injury scores and mortality of ponderosa and Jeffrey pines in 18 major study plots from 1973 - 1975--The evaluation of injury to pines in the major vegetation plots in 1973, 1974, and 1975 is shown in Tables 19a, b, and c. The paired t test was used to compare each living tree with itself between years. The highest seasonal dose yet observed in 1974 was associated with a general decline in tree score (increase in chronic injury) compared with 1973. Among the 11 plots which had significantly different mean scores (with a probability that 95 times out of 100 the difference is not due to chance) seven decreased and four increased. In 1975, there were seven mean scores significantly different. Among these, six decreased and one increased the significant differences are marked by asterisks in Tables 19a, b, and c.

The numbers of trees killed by chronic oxidant injury and associated pest complexes (including selective removal prior to pest-caused death) are shown for each year; the accumulated percentage of the original tree population killed by 1975 is also summarized (Table 19a, b, and c). The high incidence mortality at some plots with lower scores (severe injury) could be due to the earlier elimination of the individual trees most susceptible to the oxidant injury-pest syndrome. The relative incidence of different bark beetle species as causes of mortality and the relationship of injury score to bark beetle-caused mortality are discussed in the "Western Pine Bark Beetle Population Dynamics--Stand Mortality Response Subsystem" section.

Injury to white fir, incense cedar and sugar pine from 1973 to 1975--The evaluation of injury to white fir, incense cedar and sugar pine is shown in Table 20 for the 18 vegetation plots. White fir injury scores show no consistent trends from 1973 to 1975, but there are definite between-plot differences which may be due mainly to differences in oxidant dose. For example, DWA shows low score and high injury while HV shows high score and low injury. The records for incense cedar and sugar pine at five plots where each are present show generally unchanging scores from year to year with only a few examples of both increasing and decreasing

TABLE 19, a. CHANGES IN ANNUAL INJURY SCORES AND ANNUAL MORTALITY RATES OF PONDEROSA AND JEFFREY PINES AT MAJOR VEGETATION PLOTS, 1973 TO 1975.

	1973					
	Number of living trees		Number of mortalities		Year end scores of living trees	
Plot	Start	End	Oxidant related	Mechanical damage	Only	Plus oxidant related mortalities
COO	60	60	0	0	15.1	15.1
BP	72	70	2	0	16.8	16.3
CP	98	98	0	0	17.0	17.0
SF	120	119	1	0	13.4	13.3
DWA	85	85	0	0	20.2	20.2
UCC	65	65	0	0	15.5	15.5
TUN2	73	73	0	0	19.5	19.5
DL[+]	-	-	-	-	-	-
GVC	66	66	0	0	21.7	21.7
BL	137	137	0	0	29.4	29.4
NEGV	65	65	0	0	33.1	33.1
SC	62	62	0	0	41.3	41.3
HV	168	168	0	0	46.3	46.3
SCR	50	50	0	0	12.4	12.4
CA	68	67	1	0	25.6	25.3
BF(PP)	168	163	5	0	22.5	20.1
BF(JP)	58	56	1	1	21.3	20.9
CAO	124	123	1	0	24.0	24.0
HB	112	112	0	0	44.0	44.0

[+] Plot established in 1974 to replace the Snow Valley II plot badly infested with Jeffrey pine needle miner.

TABLE 19, b. CHANGES IN ANNUAL INJURY SCORES AND ANNUAL MORTALITY RATES OF PONDEROSA AND JEFFREY PINES AT MAJOR VEGETATION PLOTS, 1973 TO 1975.

	1974					
	Number of living trees		Number of mortalities		Year end scores of living trees	
Plot	Start	End	Oxidant related	Mechanical damage	Only	Plus oxidant related mortalities
COO	60	60	0	0	12.9*	12.9
BP	70	67	2	1	16.5	16.0
CP	98	92	2	4	16.7	16.4
SF	119	117	1	1	13.8	13.7
DWA	85	85	0	0	16.5*	16.5
UCC	65	64	1	0	15.9	15.6
TUN2	73	71	1	1	17.0*	16.7
DL	65	66	0	0	18.6	18.6
GVC	65	64	0	2	20.1	20.1
BL	137	137	0	0	31.8	31.8
NEGV	65	65	0	0	32.1	32.1
SC	62	62	0	0	47.3*	47.3
HV	168	166	0	2	47.7	47.7
SCR	50	50	0	0	11.7	11.7
CA	67	65	2	0	17.4*	16.8
BF(PP)	163	157	5	1	19.3*	18.7
BF(JP)	56	54	2	0	20.4	19.7
CAO	123	114	9	0	24.6	22.8
HB	112	111	1	0	39.6*	39.2

*Significant 95 times out of 100.

TABLE 19, c. CHANGES IN ANNUAL INJURY SCORES AND ANNUAL MORTALITY RATES OF PONDEROSA OR JEFFREY PINES AT MAJOR VEGETATION PLOTS, 1973 TO 1975.

	1975						
	Number of living trees		Number of mortalities		Year end scores of living trees		Accumulated oxidant related mortality 1973-1975 (%)
Plot	Start	End	Oxidant related	Mechanical damage	Only	Plus oxidant related mortalities	
COO	60	56	4	0	12.5*	11.6	6.6
BP	67	66	1	0	14.5*	14.2	6.9
CP	92	92	0	1	14.7*	14.7	2.0
SF	117	113	2	2	15.3*	15.0	3.3
DWA	85	83	2	0	16.0	15.7	2.4
UCC	64	64	0	0	16.3	16.3	1.5
TUN2	71	70	1	0	17.0	16.8	2.7
DL	66	65	1	0	19.2	18.9	1.5
GVC	64	64	0	0	23.1*	23.1	0
BL	137	136	1	0	30.5*	30.3	0.7
NEGV	65	64	1	0	40.6*	40.0	1.5
SC	62	62	0	0	44.5*	44.5	0
HV	166	166	0	0	44.6*	44.6	0
SCR	50	49	1	0	12.5	12.3	2.0
CA	65	64	1	0	17.9	17.6	5.9
BF(PP)	157	155	2	0	20.5*	20.2	7.1
BF(JP)	54	53	1	0	21.5	21.1	6.9
CAO	114	113	1	0	25.7	25.5	8.9
HB	111	111	0	0	33.9*	33.9	0.8

TABLE 20. OXIDANT INJURY SCORES OF WHITE FIRS, INCENSE CEDARS, AND SUGAR PINES AT 18 MAJOR STUDY PLOTS, 1973-1975.

Plot	White Fir average injury score			Incense Cedar average injury score			Sugar Pine average injury score		
	1973	1974	1975	1973	1974	1975	1973	1974	1975
SCR	52.9	52.1	53.1	---[*]	----	----	----	----	----
COO	47.2	47.2	49.2	30.3	29.7	29.7	----	----	----
SF	40.7	42.5	46.6[+]	24.4	25.2	27.2[+]	35.5	34.6	40.2[+]
UCC	----	----	----	----	----	----	----	----	----
BP	----	----	----	27.4	27.1	28.2[*]	----	----	----
CP	----	----	----	----	----	----	----	----	----
DWA	37.9	37.1	39.8	20.7	24.2[*]	25.1[+]	60.0	44.7	41.0[+]
TUN2	49.3	51.5	55.5	----	----	----	37.6	38.0	35.2
CA	55.6	54.8	52.9	----	----	----	39.0	27.8	28.8
BF	----	----	----	----	----	----	----	----	----
SV	52.7	54.0	ND[‡]	----	----	----	----	----	----
DL	ND	55.6	56.8	----	----	----	ND	39.3	42.5[+]
GVC	53.6	52.0	52.5	29.2	27.6[+]	28.2	36.0	30.7[+]	33.7
CAO	48.6	42.7	48.6[+]	----	----	----	----	----	----
BL	58.0	56.4[*]	58.8[+]	----	----	----	----	----	----
NEGV	66.6	64.5	65.6	----	----	----	----	----	----
HB	48.7	51.5	49.7	----	----	----	----	----	----
SC	62.3	59.2	59.6	----	----	----	----	----	----
HV	63.7	61.8	60.2	----	----	----	----	----	----

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[*] Blank means that the species is not present.

[+] Significant, 95 times out of 100.

[‡] ND = No data.

scores.

We do not have meaningful verbal descriptions (e.g., slight, moderate, severe) which can be applied to the score ranges of these species. No incidents of death of these three species which can be related to oxidant injury have been observed. Oxidant injury to white fir and incense cedar foliage is simply more difficult to estimate visually since the chlorotic mottle pattern is not very distinct. Chlorotic mottle is the element of the score which is weighted most heavily. Efforts are under way to improve the methodology for describing oxidant injury to conifers other than pines.

Oxidant Injury to Associated Vegetation--

Woody--Both shrub and tree species were inspected throughout the summer and autumn. Skunk bush (*Amorpha californica*) was the only shrub layer species which showed ozone-like injury. Among the trees, the oaks (*Quercus crysolepis* and *Q. wizlizenii*) and dogwood (*Cornus nutallii*) displayed no definite symptoms, but black oak (*Quercus Kellogii*) began to show chlorotic mottle in 1974 with some interveinal necrosis as early in the growing season as August 9, 1974 in the western section of the study area.

Herbaceous--During the spring and summer, 1974, all 18 vegetation plots and adjacent areas were routinely inspected as new plants emerged and flowered. Ozone or PAN symptoms were observed on 11 species: *Bromus orcuttianus*, *Elymus glauca*, *Osmorhiza chilense*, *Gallium aparine*, *Erigeron breweri*, *Potentilla glandulosa*, *Solidago sp*., *Vicia californica*, *Artemisia douglasiana*, *Silene verecunda*, and *Collomis grandifolora*. Seeds were collected from six of the above species which occur in the greatest abundance. Ozone and PAN injury symptoms must eventually be confirmed by fumigation experiments on young plants grown in the greenhouse from this seed.

STAND TREE GROWTH SUBSYSTEM

Introduction

An understanding of the impact of oxidant air pollutants on mixed conifer forest ecosystems depends on knowledge of the growth, composition, and succession of the vegetation. First, we need to know how air pollutants affect growth of vegetation because this also affects the ability of different plant species to complete with one another for the resources they require (ecosystem dynamics). As a result of this competition, particular species compositional patterns occur (ecosystem structure). Over time, these compositional patterns change and result in vegetational succession (ecosystem behavior).

Research Objectives

Several objectives were selected which would help to understand the effects of chronic oxidant injury on the growth and productivity of ponderosa and Jeffrey pines. These included:

1) Determine the growth differences of ponderosa pine saplings maintained in carbon-filtered and oxidant-polluted atmospheres;

2) Compare the radial and vertical growth of two groups of polesize ponderosa pines between 20 and 39 years old for the periods 1910 to 1940 and 1941 to 1971, before and after the influence of oxidant injury;

3) Compare radial growth of sawtimber sized ponderosa pines with amount of chronic injury to the crown expressed as an oxidant injury score;

4) Examine Forest Service estimates of timber volume loss at two plots over a 20-year span from 1952 to 1972.

Materials and Methods

Growth in Oxidant Polluted and Unpolluted Atmospheres--

Ponderosa pine saplings inside and outside of greenhouses--In August, 1968, two greenhouses were erected over natually established ponderosa pine saplings near Rim of the World High School (0.4 km east of Rim Forest). Each greenhouse was approximately 3.7 x 3.7 m at the base and 4.0 m high. From mid-April to mid-November during each year from 1969 to 1973, the greenhouse frames were covered with Mylar or Kreen plastic film. During the winter months, when the panels were removed, the oxidant dose was usually not greater than background (0.03 ppm) and the saplings received normal precipitation; summer precipitation was usually negligible. A group of 10 saplings near the greenhouses were used as an ambient air outside (AAO) treatment. Study methods and results of observations of needle symptom development on the AAO group have been included in the preceding section (Oxidant Flux-Canopy Response Subsystem). During the summer of each year, greenhouses were force ventilated continuously; one received unfiltered ambient air (AAH) and the other received carbon-filtered air (FAH). Oxidant concentrations in the FAH treatment never exceeded about 10% of the ambient concentration. Occasional applications of malathion were needed to control aphid populations. Injury to current and one-year-old needles of trees in each treatment was measured at the end of each season. At the end of the 1973 growing season, all but three saplings from each treatment were harvested to compare (1) needle biomass for internodes of the same age, (2) length of annual growth of the terminal shoot and (3) first order branches, and radial growth response. The latter was done by measuring annual ring widths on a section cut from all internodes dating as far back as 1956. A nearby monitoring station at Rim Forest documented the oxidant dose during June through September each year (Fig. 21).

Radial and vertical growth of polesize ponderosa pines before and after inception of oxidant injury--Two tree populations near the Dogwood (DWA) plot were used in the study. As of 1972, one population ranged in age from 52 to 71 years old and the other from 20 to 39 years old. Nineteen dominant trees were selected from each population and an increment core sample was removed from the south side of each tree. Ring widths were measured on these cores to the nearest 0.01 mm with a dendrochronograph. An average ring width was calculated for the 52 - 71 year-old population for rings produced from 1910 to 1940. This period was characterized by low oxidant concentrations in the San Bernardino Mountains. During this period, the trees in the 52 - 71 year-old population became established and produced 20 to 39 annual rings.

An average annual ring width was calculated for the 20 - 39 year-old population for rings produced from 1941 to 1971. This period was characterized by high oxidant concentrations in the San Bernardino Mountains. During this period, the trees in the 20 - 39 year-old population became established and produced 20 to 30 annual rings. Rainfall data for these two periods was also obtained for a nearby station so that the contribution of precipitation to growth could be evaluated during each period.

Relationship of Oxidant Injury Scores of Co-dominant and Dominant Ponderosa Pines to Radial Growth--

Increment cores were taken from the south side of 102 dominant and co-dominant ponderosa pine trees near the DWA plot; these trees were in a plot designated DWB. Annual ring width was measured to the nearest 0.01 mm on the cores with a dendrochronograph. The correlations between current (1974) annual ring width and current oxidant injury score, and current (1974) annual ring width and average oxidant injury score (1969-74) was determined using a regression analysis based on the method of least squares.

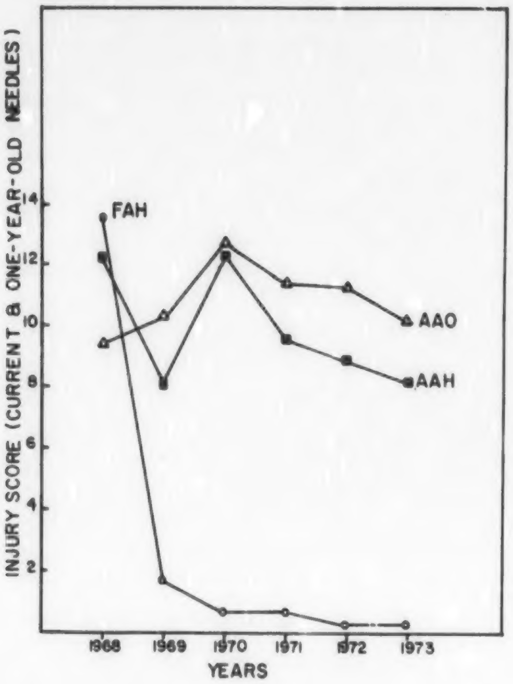


Figure 43. Injury score of current plus one-year needles, 1968-1973, from ponderosa pine saplings maintained in filtered (FAH) or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

Changes of Timber Volume Assigned to Four Insect Risk Categories in Two Jeffrey Pine Stands Between 1952 and 1972--

Two 5 acre control plots were established by the Forest Service in the Barton Flats (BF) area in 1952 to evaluate a four-category bark beetle risk rating procedure. These plots are in the Jeffrey pine-white fir subtype and are now considered to be in an area of moderate oxidant injury (our CAO plot is nested within control plot 2). All Jeffrey pines, with a diameter breast height (dbh) of 12 in (30.5 cm) and larger were measured and their vigor was described by judging the risk or the probability that they would be susceptible to attack and kill by bark beetles (*Dendroctonus spp*). Risk classes 1 and 2 indicate low-risk trees that would definitely be preserved if trees were being marked for a timber sale. Class 3 and 4 are high-risk trees that would be marked for removal in a timber sale. The trees which remained were observed by the Forest Service again in 1963 and 1972 and were reassigned to the appropriate risk category. The tree characteristics used for the risk rating procedure and oxidant injury scoring are generally analogous, so these observations can be used as indicators of the chronic effects of oxidant injury.

Results and Discussion

Growth in Oxidant Polluted and Unpolluted Atmospheres--

Ponderosa pine saplings inside and outside of greenhouses--At the outset of the experiment in August, 1968, most trees retained only 1967 and 1968 annual needle complements with severe oxidant injury symptoms, namely chlorotic mottle, necrosis, and premature abscission of needles shorter than normal. In the following years, the new needles growing in the FAH treatment failed to develop injury symptoms and were distinguished by their longer length, healthy green color, and lower oxidant injury scores compared to the AAH and AAO treatments (Fig. 43). The slightly lower level of needle injury to AAH than to AAO suggests that enclosure in a force-ventilated greenhouse without air filtration had some positive benefit compared to AAO saplings growing outside and adjacent to the greenhouses.

At the end of the 1973 growing season after saplings were harvested, needle biomass was compared for internodes of the same age. Increases of needle biomass in the FAH treatment for the one-year-old (1973) needle complement compared to AAH and AAO trees (Fig. 44) became significantly greater (95 times out of 100 by 1973. Needles in internodes older than 2 years were completely absent in the AAH and AAO treatments.

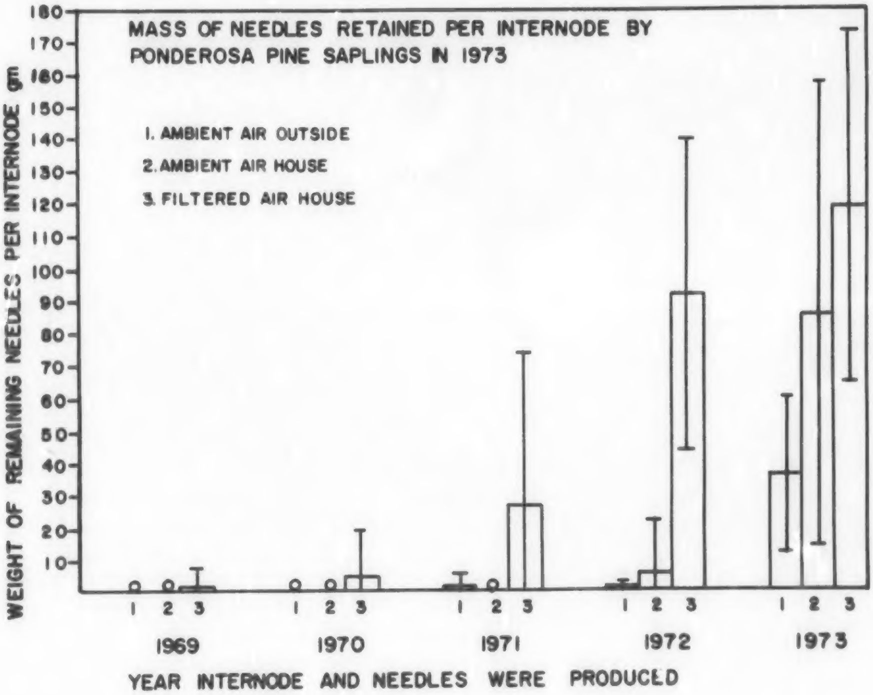


Figure 44. Average dry weight of all needle fascicles per internode in filtered (FAH), or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

The dramatic decrease in needle leaf biomass in the AAO and AAH treatments represents severe reductions of photosynthetic capacity. Conversely, as more leaf biomass was produced in the FAH treatment, more carbohydrates could be produced and used for the growth of woody tissue. After a long lag period, lengths of the terminal shoots (Fig. 45, upper) and first order branches (Fig. 45, lower) of the upper half of tree crowns in the FAH treatment increased significantly (95 cases out of 100). Terminal and branch growth of trees in the AAH and AAO treatments remained the same or lower. The general relationships of terminal and radial growth to precipitation and oxidant dose are presented in Figure 46. During the period 1956 to 1968, the annual ring width of all saplings destined to be included in the FAH, AAH, and AAO treatments declined gradually.

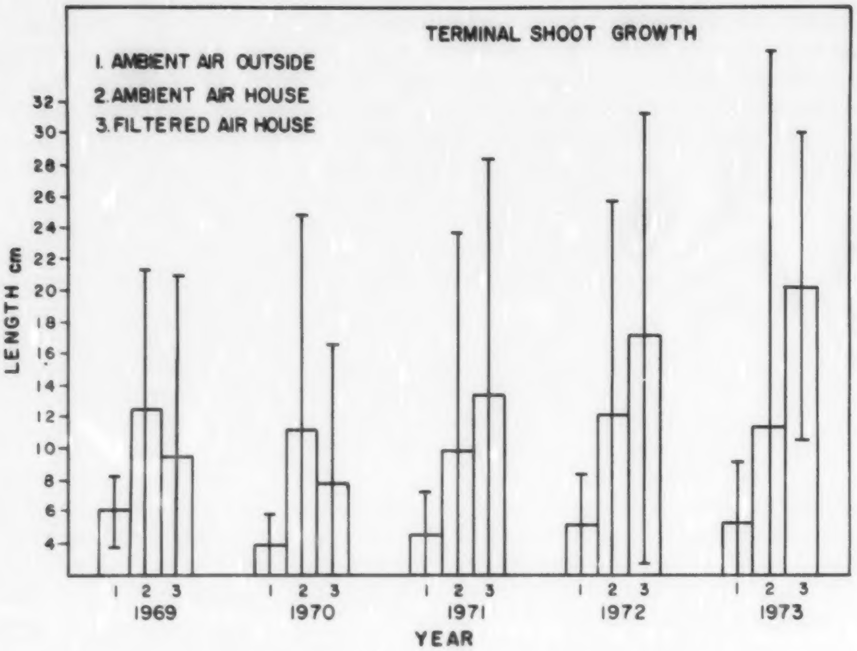
Each data point is the average of the ring width of all internodes in each year; this offers a more reliable estimate of radial growth trend (Duff and Nolan, 1954). From 1968 to 1972, radial growth in the FAA treatment is remarkably larger than in either the AAH or AAO treatments. The improved radial growth in the AAH treatment suggests that some greenhouse effect is helpful in reducing injury to foliage (Fig. 46) and subsequent radial growth. The reduction of growth during 1963 in both the FAH and AAH treatments may be related to increased competition for water as the trees grew larger, in combination with an uncontrolled aphid infestation.

Terminal shoot growth appears to have a light upward trend from 1956 to 1972. In the FAH treatment, there was a time lag of 3 years before the terminal growth reflected a significant response to the carbon-filtered air. The terminal growth response in the AAH treatment also showed some benefit from enclosure in the greenhouse with polluted air.

The expected correlation between rainfall and both types of growth can be identified throughout the 1956 to 1972 period, but a multivariate analysis is needed to further quantify the effects of precipitation, temperature, and oxidant dose on growth. Between 1964 and 1973, growth responses in the AAO treatment track the precipitation trend quite well. It was difficult to judge the relative effects of decreasing oxidant dose and increasing precipitation on the gradual terminal and radial growth increases in the AAO treatment between 1970 and 1973. The over-riding conclusion from this study is that the FAH treatment resulted in dramatic increases in needle biomass retained on the trees and subsequent increases in both radial and terminal growth. Finally, the year-to-year trend of injury to current year needles follows the seasonal oxidant dose trend in the lower right corner of Figure 46. The small number of replicates in this study limits extrapolation of these results to other saplings. But terminal growth of 20 - 30 ponderosa and Jeffrey pine saplings will be measured non-destructively in each of 12 plots near certain of the 18 vegetation plots.

Radial and Vertical Growth of Polesize Ponderosa Pines Before and After the Inception of Oxidant Injury--

Table 21 shows a comparison of the radial growth of ponderosa pine in



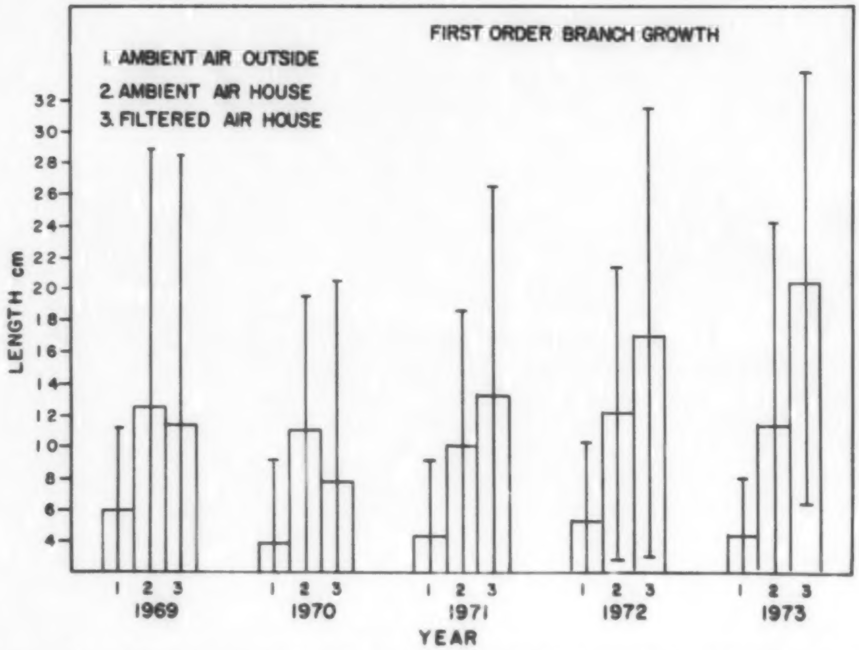


Figure 45. Annual growth of terminal shoot (upper) and first order branches (lower) in upper half of sapling from ponderosa pine maintained in filtered (FAH), or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

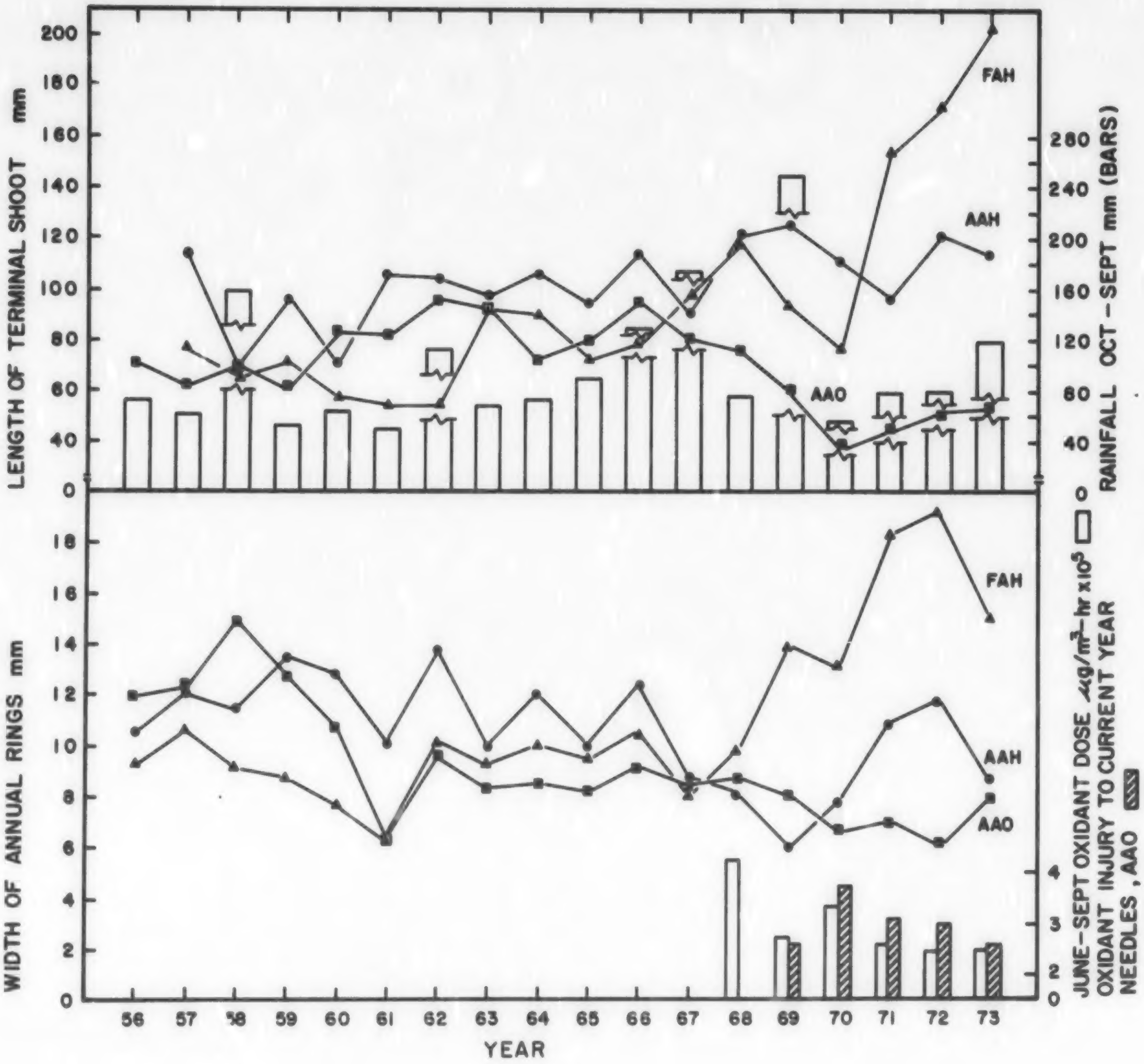


Figure 46. Relationship of precipitation, oxidant dose and foliar injury to radial and vertical growth of ponderosa pine saplings before and after treatments in filtered (FAH), or unfiltered air greenhouse (AAH), and an outside ambient air treatment (AAO).

TABLE 21. AVERAGE ANNUAL RADIAL GROWTH OF 19 PONDEROSA PINE TREES IN TWO LEVELS OF OXIDANT AIR POLLUTANTS.

High Pollution		Low Pollution	
Age* (years)	Average radial growth (cm) 1941-1971	Age* (years)	Average annual radial growth (cm) 1910-1940
20	0.20	60	0.52
21	0.33	55	0.49
29	0.22	55	0.61
22	0.33	57	0.34
25	0.30	64	0.40
35	0.23	63	0.55
27	0.29	60	0.44
28	0.31	65	0.46
35	0.26	60	0.75
22	0.43	71	0.67
39	0.21	63	0.71
35	0.34	71	0.65
29	0.37	66	0.78
33	0.37	63	0.53
35	0.34	60	0.33
35	0.37	70	0.38
36	0.35	61	0.32
36	0.33	62	0.37
34	0.36	59	0.37

*Age at 1.4 m above ground in 1971.

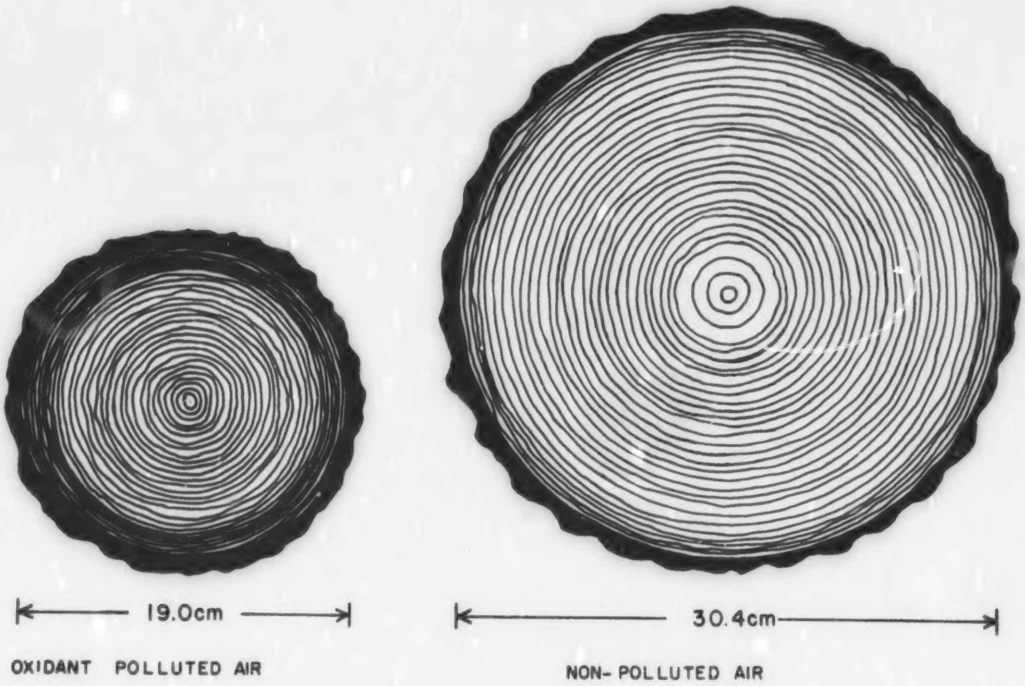


Figure 47. Calculated average cross-sections of two 30-year-old ponderosa pines at breast height grown in polluted air (left) and in non-polluted air (right) based on radial growth samples from 1941-1971 and 1910-1940.

environments characterized by low air pollution (1910-1941) and high air pollution (1941-1971).

The average annual rainfall between 1910 and 1940 was 110.9 cm per year, and from 1941 to 1971 was 117.4 cm. A difference of 0.20 mm in average annual growth occurred between the two periods. Average 30-year-old trees grown in the two periods would have diameters of 30.5 cm and 19.0 cm (Fig. 47). The difference in these diameters is attributed to the influence of air pollutants during the period 1941 to 1971. This information, along with the height growth data from the saplings in greenhouses can be combined to approximate the reduction in volume growth in ponderosa pine trees near the Dogwood plot. An average 30-year-old tree grown under the present air pollution conditions would be 7.0 m tall, 19.0 cm in diameter at breast height, and could produce one log 1.8 m long with a volume of 0.047 m^3 (Fig. 48). An average 30-year-old tree grown in the absence of oxidant air pollutants (i.e., 1910-1940) would be 9.1 m tall, 30.5 cm in diameter and could produce one log 4.9 m long with a volume of 0.286 m^3 (Fig. 48).

Relationship of Oxidant Injury Scores of Co-dominant and Dominant Ponderosa Pines to Radial Growth--

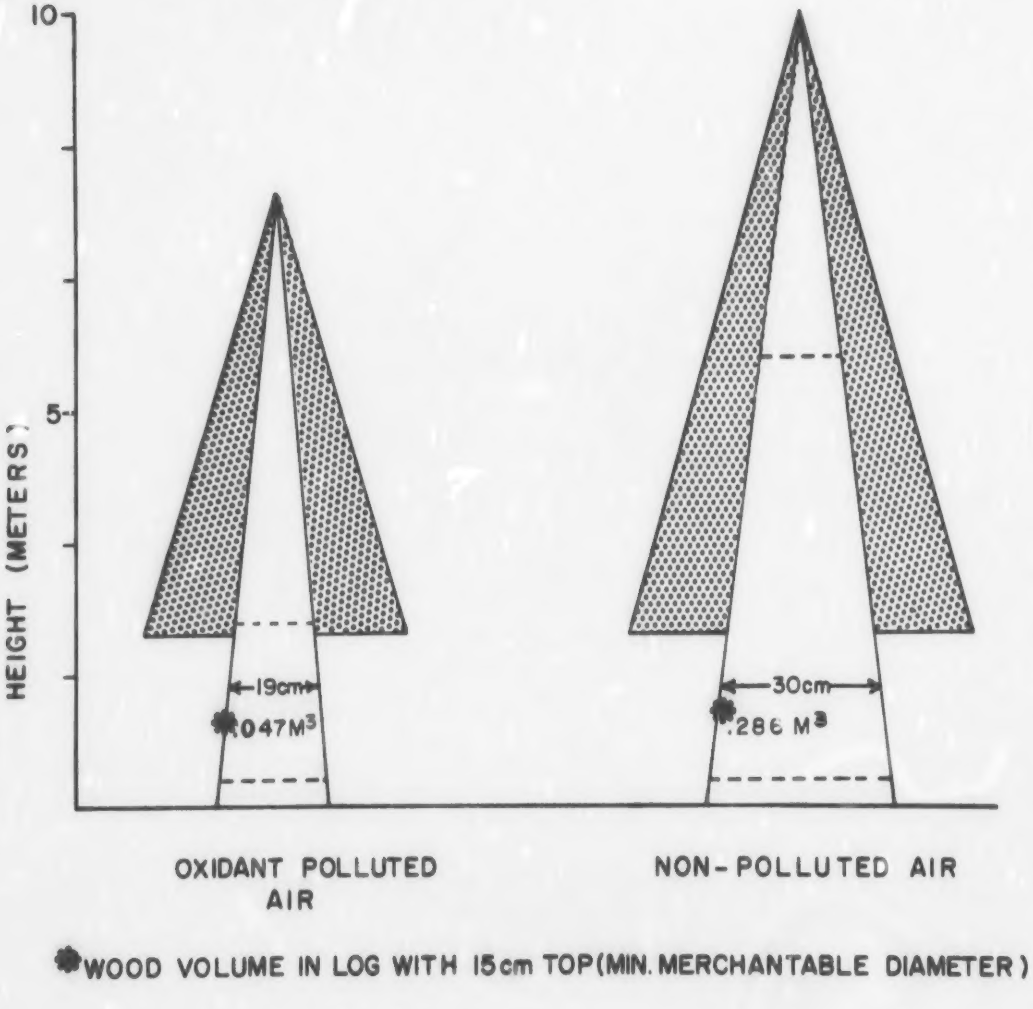

10
5
HEIGHT (METERS)
19cm
.047M^3
30cm
.286 M^3
OXIDANT POLLUTED AIR
NON-POLLUTED AIR
WOOD VOLUME IN LOG WITH 15cm TOP (MIN. MERCHANTABLE DIAMETER)

Figure 48. Calculated average growth of 30-year-old 15 cm ponderosa pines in polluted and non-polluted air based on radial growth samples from 1941-1971 and 1910-1940.

This study of radial growth has attempted to correlate ring width with the oxidant injury score of individual trees in the Crest Park area at the DWB plot. The low r-values (Table 22) obtained in both tests indicate that crown characteristics assessed by oxidant injury scoring (Miller, 1974) are not closely correlated with radial growth. This result is difficult to understand in view of the general correlation between photosynthetic area and radial growth in forest trees as discussed by Kramer and Kozlowski (1960). The oxidant injury scoring method used may involve the measurement of characteristics which have little impact on radial growth, but which contribute significantly to the calculated oxidant injury score. The influence of each score component should be tested separately, e.g. needle retention and needle condition. A preliminary attempt at correlating precipitation and oxidant level with ring width was inconclusive (McBride, 1974). A larger sample of tree cores has been collected and the annual ring widths are being measured. Variations in temperature, precipitation, and oxidant level will be used in a principal component analysis (Fritts, 1974) to determine their respective effects on radial growth.

TABLE 22. CORRELATIONS BETWEEN PONDEROSA PINE RADIAL GROWTH (Y) IN CENTIMETERS AND OXIDANT INJURY SCORE (X).

Independent variable	Regression equations	r
Current year oxidant injury score (1974)	$Y=0.12 + 0.06X$	0.51
Average oxidant injury score (1969-74)	$Y=0.10 + 0.06X$	0.51

Changes of Timber Volume Assigned to Four Insect Risk Categories in Two Jeffrey Pine Stands Between 1952 and 1972--

This is the longest observational record of tree decline available, although it was not designed initially to evaluate chronic oxidant injury. In Table 23, the changes in merchantable volume in board feet (bd ft) in all four classes are recorded for two control plots in 1952, 1963, and 1972. The increases in volume of high-risk trees since 1952 are remarkable; decreases in volume of low-risk trees and total volume in the plots are very large. The total volume decrease is related (1) to one-by-one removal of bark-beetle-killed trees inside the plots indicated for certain by the increase in snags and current stumps, and (2) possibly to suppressed radial growth. The 1973-1975 accumulated mortality at our Camp Osceola (CO) plot nested within control plot 2 has remained high (8.9%) even though the average oxidant injury score was 25.7 (slight) in 1975.

TABLE 23. CHANGES OF TIMBER VOLUME AND PERCENTAGE OF TOTAL JEFFREY PINES IN FOUR BARK BEETLE RISK CLASSES AT TWO CONTROL PLOTS EXCLUDED FROM SANITATION SALVAGE LOGGING BETWEEN 1952 AND 1972 AT BARTON FLATS IN THE SAN BERNARDINO NATIONAL FOREST.

	Control Plot 1 (JCA Camp, Highway 38)					
	1952		1963		1972	
Risk Classes	Timber volume, bd ft	Percentage of trees	Timber volume, bd ft	Percentage of trees	Timber volume, bd ft	Percentage of trees
Total, all classes	73,040	100	63,530	100	52,730	100
Risks 1 and 2	58,520	87	38,700	73	23,780	55
Risk 3	6,740	7	14,630	13	14,140	16
Risk 4	7,780	5	10,200	7	14,810	20
Snags and current stumps*	1	1	11	7	13	8

	Control Plot 2 (Camp Oceola Road)					
Risk Classes	1952		1963		1972	
Total, all classes	120,130	100	112,660	100	112,930	100
Risks 1 and 2	110,830	93	98,080	82	45,670	32
Risk 3	5,990	3	10,170	6	37,420	30
Risk 4	3,310	2	4,410	6	29,840	28
Snags and current stumps*	3	2	13	6	18	10

*Accumulation during 10-year period. Data obtained from the Supervisor's Office, San Bernardino Forest.

STAND MOISTURE DYNAMICS AND MICROCLIMATE SUBSYSTEMS

Introduction

Within Season Trends of Soil Moisture Availability and Soil Temperature--

We set out to examine the interaction of climate with soil and possible drought-stress which can occur simultaneously with the impact of oxidant air pollution on the ecosystem. The first step was to document the macroclimate in terms of precipitation and temperature and the microclimate in terms of soil moisture and soil temperature regimes, and the system's consequent water balance.

Within Season Microclimate and the Trend of Predawn Xylem Water Potential--

We hypothesize that one of the most important factors controlling the amount of ozone injury to conifer foliage in a single growing season is the pattern of stomatal behavior. A transpiration model developed by Reed and Waring (1974) provides a method of simulating transpiration by using the inputs of seasonal trends in predawn xylem water potential, a submodel of stomatal function, and daily records of temperature and relative humidity. Bennett and Hill (1975) reviewed the literature supporting the hypothesis that increased transpiration results in increased pollutant uptake. Our seasonal data will provide a means of quantifying the "effectiveness" of an ozone dose during different times of the growing season and will be important input to the "Oxidant Flux-Canopy Response Subsystem."

Materials and Methods

Soil Moisture and Temperature Measurements--

Soil moisture-temperature sensors (fiberglas moisture blocks) were installed in auger holes at depths of 15, 30, 61, 92, 152, 214, and 274 cm (6, 12, 24, 36, 60, 84, and 108 in). The holes were repacked with the same soil to as close to its original thickness and density as possible. Readings were taken every 1 to 3 weeks since the spring and summer of 1973 depending upon the rate of change of the soil moisture. Soil taken from the cores was used to calibrate the moisture sensor readings with water content. In spring and fall, soil cores were collected at 23 sites either to the depth of hard bedrock or to a depth of 2.75 m (9 ft), for measurement of maximum and minimum water holding content, and for physical and chemical analysis. Water content was determined by weight differences in oven-dried samples, and the total volumetric water content was calculated for the entire soil core as corrected for gravel or stones. These data provide a true estimate of the storage capacity of soil water which is usable by plants.

Predawn Xylem Water Potential Measurement--

Monthly during July, August, and September, 1975, predawn xylem water potential was measured on two ponderosa or Jeffrey pines at each of three plots: Camp Angelus, Camp Oceola, and Heart Bar. In 1976, the same measurements were made bi-weekly at the same plots and at three others: Tunnel 2, Dogwood, and Deerlick. Continuous temperature and relative humidity data were measured using hygrothermographs and an electric psychrometer at adjacent stations in both years and at the time of water potential measurements. A bomb patterned after that used by Scholander, et al. (1965) was used to measure the water potential of branch tips excised with a pole pruner from heights between 3 to 5 m above ground. At the same time, stomatal infiltration pressure was determined using an infiltration porometer (Fry and Walker, 1967) for both current and one-year-old needles of each excised branch tip. The trees selected for sampling had slight or no injury (their scores were larger than 21).

Results and Discussion

Trends of Soil Moisture Availability and Soil Temperature--

Soil moisture--An example of results obtained at one site from the fiberglas moisture-temperature sensors installed at 23 sites throughout the study area is shown in Figure 49. Moisture curves were obtained by a comparison of field readings (conductivity converted to resistance and corrected for temperature by computer) with soil samples from the same site at varying moisture contents. Moisture curves for 3 depths show the drying period from March to October for 1973 and 1974. In both years, the effect of light rains wetting the upper 15 cm of soil during April and May is evident, while rain in May affected the sensor at 91 cm (36 in) only in 1973. The toal amount of rain which produced these effects was only 20 mm (0.79 in) in 1973, recorded 1.5 km away at Lake Arrowhead. In May, 1974, rain amounting to only 7.0 mm (0.28 in) produced the rise in the curve in late May. The sensitivity of the method is quite evident.

The curves show clearly that the maximum rate of water use by vegetation occurs during June and early July, and that after mid-July, the soil dries very slowly. From mid-July to late fall the upper 150 cm of soil is at or near permanent wilting point. At another site, sensors placed to a depth of 275 cm (9 ft) showed that moisture extraction continued slowly into September; this suggests that the forest survives the summer drought by extracting moisture from deep in the decomposed granite substratum. The drastically reduced rate of water use after mid-August indicates that the forest is essentially dormant at least until after the first precipitation in autumn. Future comparisons of soil moisture availability and transpiration determined by the Reed and Waring (1974) simulator will further refine the interpretations of vegetation response.

The spring period during which soils contain available soil moisture in 1974 is shown by black bars in Figure 50. These data were also obtained from the sensors and indicate that essentially all available soil moisture was exhausted from the soil in 11 plots before mid-August. The date was determined by examining the computed resistance of the moisture sensors; the first date at which the sensor was found to have a resistance of 100,000 ohms was taken to represent the date after which soil moisture

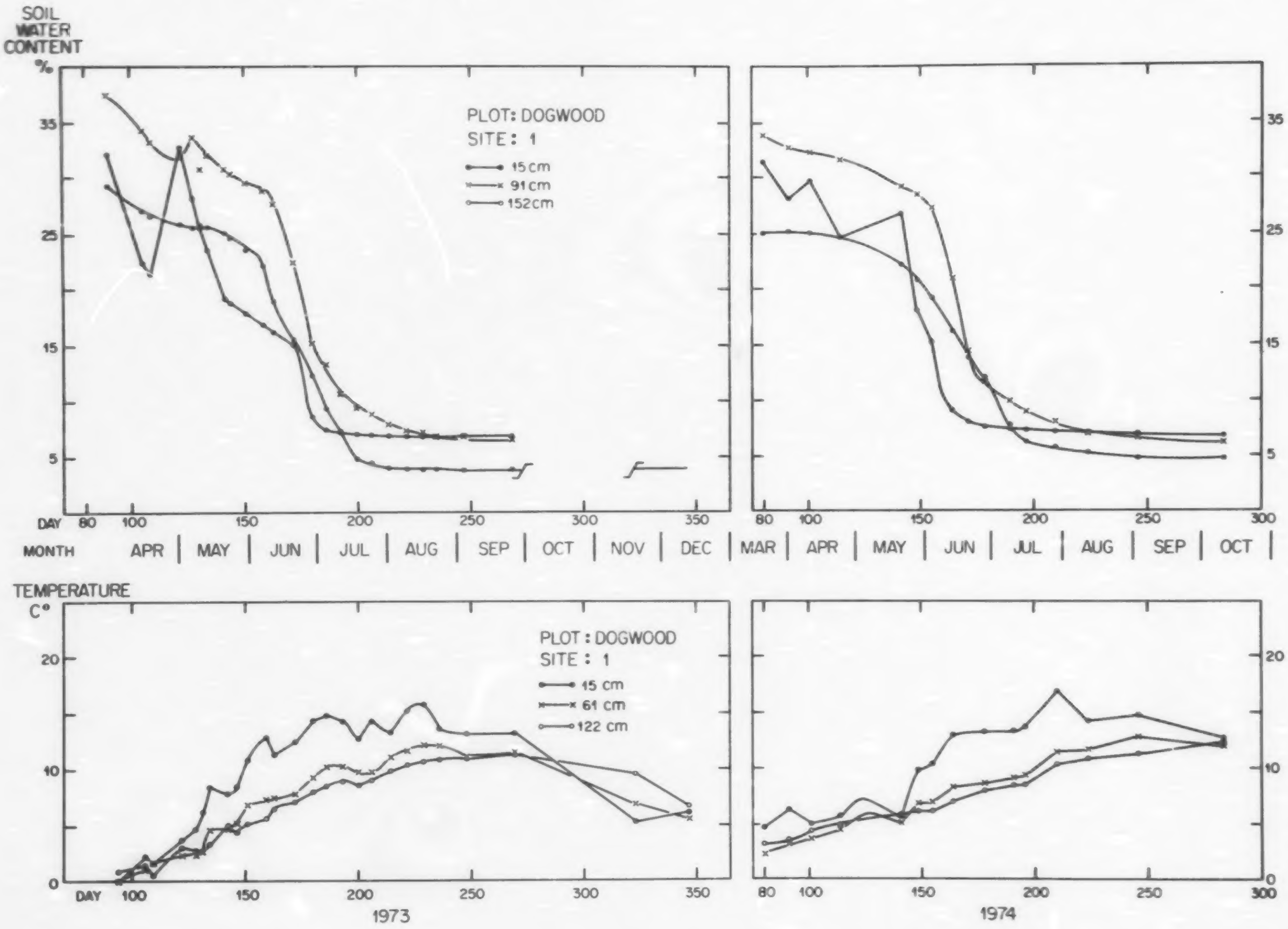


Figure 49. Soil moisture and temperature regime 1973-74 at Dogwood plot.

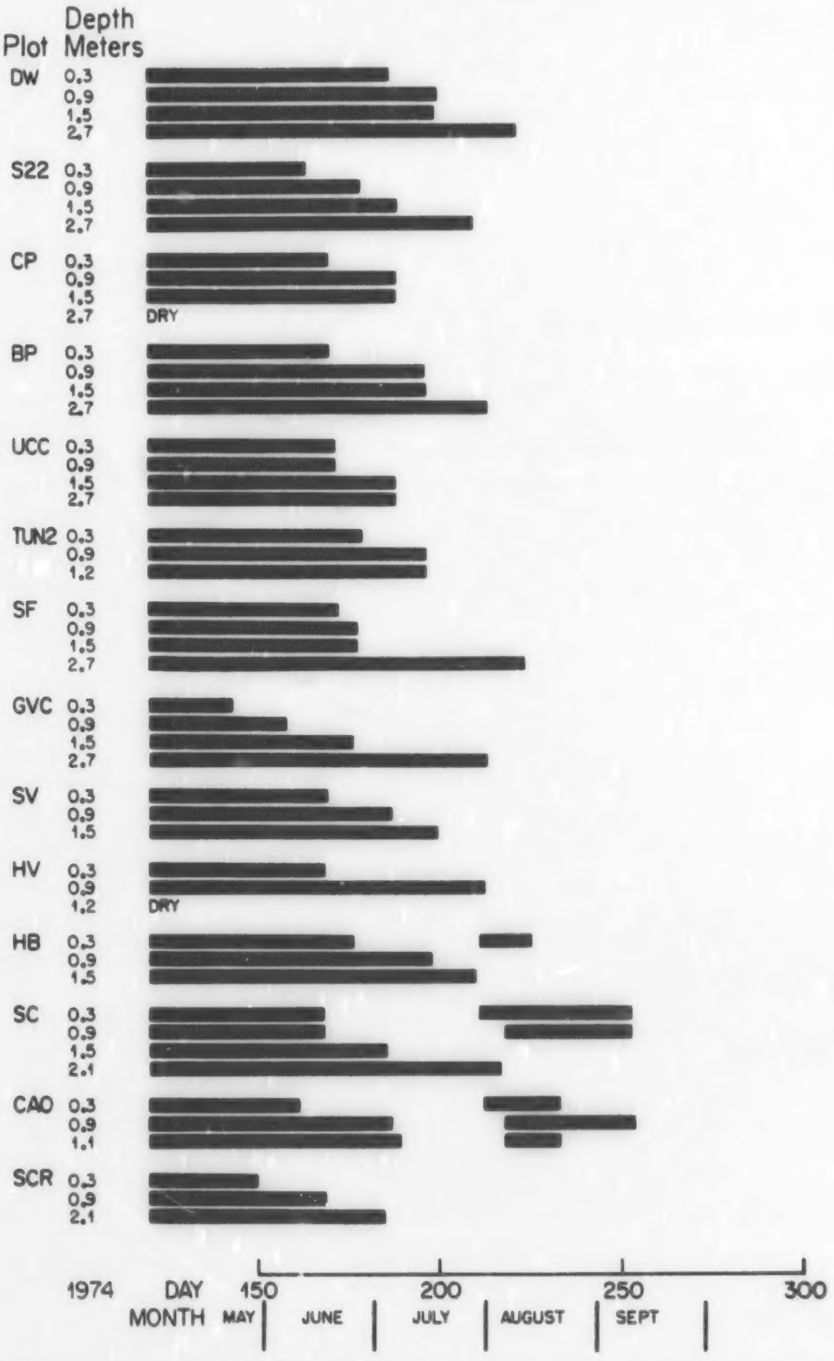


Figure 50. Time intervals during which the soil at various depths contained moisture available for plants during spring and summer 1974.

depletion was at a minimum rate. Three of the sites -- Heart Bar (HB), Sand Canyon (SC1), and Camp Osceola (CAO) -- were wet by summer thunderstorms in late July and early August. This rain probably had little effect at HB as only the upper 30 cm (1 ft) was moistened. However, SCR and CAO were wet to a depth of about 1 m at a time when the deep soil moisture was nearly exhausted. Thus, the period of active growth may be prolonged by summer thunderstorms, which occur mainly in the eastern portion of the San Bernardino Mountains near Big Bear Lake and in Santa Ana Canyon. August precipitation exceeding 25 mm at Big Bear Lake Dam occurs with a frequency of about 23%, while at Lake Arrowhead it is about 14%.

The significance of these data in relation to air pollutant impact is that the most dynamic growing period for conifers and vegetation is from early May, when soil temperatures begin to rise, through August, when soil moisture is often exhausted. Thus, one could expect the most severe damage to the plants by air pollutants to take place during this period.

Soil temperature--Soil temperature measurements at the Dogwood plot obtained with the soil moisture-temperature sensors are also shown for 3 soil depths in Figure 49, which is representative of the Lake Arrowhead area. The curves show that soils were colder in April, 1973 than they were in April, 1974. Soil temperature during 1973 rose smoothly to a maximum in August, whereas in 1974, they were held down by a cold period in May, followed by a sharp rise in surface temperature with the maximum (below the surface layer) delayed into September. A marked soil temperature difference due to aspect is shown by the fact that in September, 1974, soil temperature in the upper part of the soil was 7.7 C higher at plot S22 than at the Dogwood plot. Plot S22 is near Dogwood, but has a south-facing slope.

Preliminary inspection of the data indicates that in September, at the Bluff Lake plot, located high above Big Bear Lake at an elevation of 2260 m (7400 ft), the soil temperature was 3.6 C lower than at Dogwood; at Holcomb Valley, on the desert side of Big Bear Lake, it was about 3.8 C higher; Camp Angelus in the Santa Ana Canyon, which is at about the same elevation as Dogwood, was about 2.4 C higher. Detailed comparisons of the soil temperature regimes at all plots will be completed soon.

Soil Moisture and Temperature Data Collected in 1975 and 1976--

Soil moisture and temperature readings continued to be made at 23 sites including the major vegetation plots. It was hoped that by this time, all data might have been computer processed so that the soil moisture and temperature regimes and their relationships to climate and air pollutant impacts might be shown. However, the arrangement for data processing with the Lawrence Livermore Laboratory has been less than satisfactory. As a result, these data collected since 1973 have been processed preliminarily, but virtually all have been stored in the computer in the requested form. As a consequence, excellent data have been collected, but their application for the purposes of the project await effective final data processing. The amount of data awaiting computer processing is on the order of 10,000 sensor readings.

Predawn Xylem Water Potential of Ponderosa and Jeffrey Pines at Selected Sites--

Xylem water potential trends, 1975 and 1976--The data from 1975 and 1976 in Figures 51 and 52 show the increases of air pressure (bars) required to force water from excised branch tips as the season progressed and soil moisture availability diminished. The higher values in the early 1976 season cannot be explained with certainty at this time. The predawn period provides an opportunity to observe the highest water potential (lowest scale value in bars) for the 24 hr period. The general relationship of lower water potentials (higher scale values) and the gradual raising of the daily temperature maxima as the season progresses can be observed in the 1976 data (Fig. 52).

Data inputs to a transpiration model--The stomatal infiltration data gathered during predawn periods and also for all daylight hours on several other sample days is required for the submodel of stomatal behavior (Reed and Waring, 1974). Stomatal infiltration data can be converted with some uncertainty to stomatal resistance. A diffusion porometer is a better instrument (Slavik, 1974) and one has just become available to our subproject. We will use it to calibrate existing data from the infiltration porometer and to obtain the additional data needed to plot a regression between predawn xylem water potential and the minimum daily stomatal resistance for corresponding days. Infiltration data will not be reported here, but several comparisons have been made, including: different heights in trees, sunny and shaded sides, different tree sizes, different annual needle whorls, and different levels of oxidant injury.

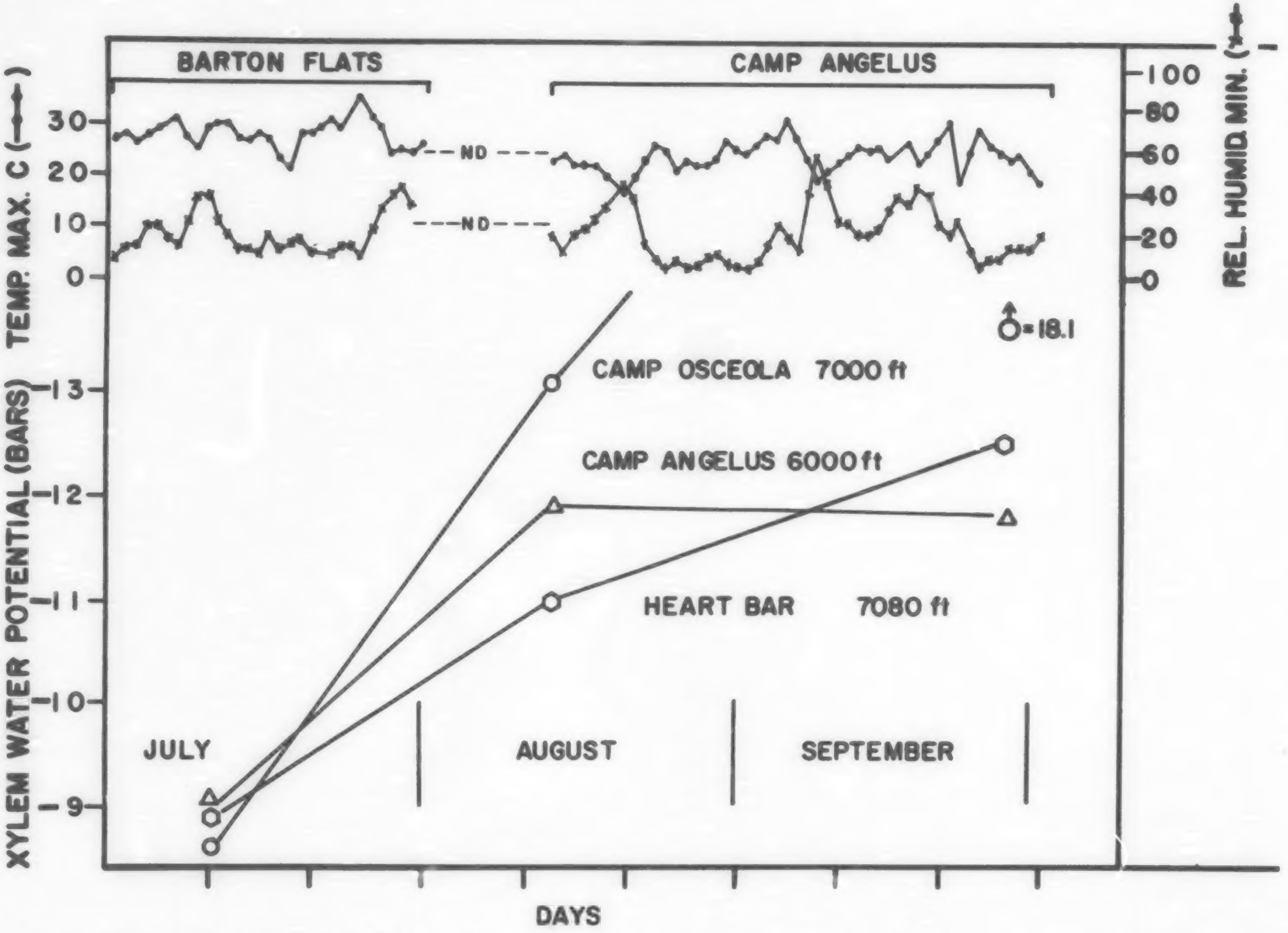


Figure 51. Ponderosa and Jeffrey pine predawn xylem water potential at three plots in 1975 in relation to daily temperature maximums and relative humidity minimums.

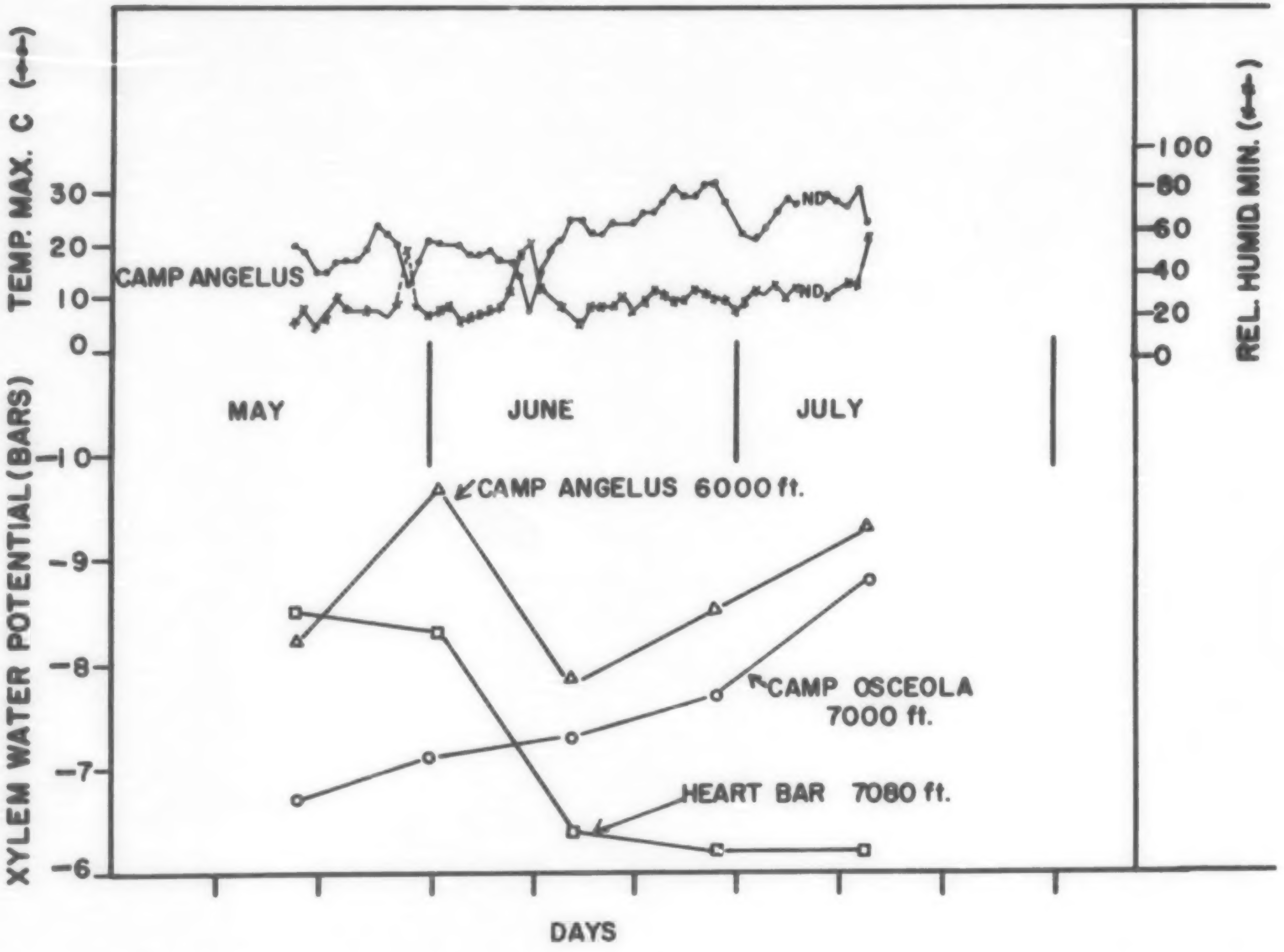


Figure 52. Ponderosa and Jeffrey pine predawn xylem water potential at three plots in 1976 in relation to daily temperature maximums and relative humidity minimums.

WESTERN PINE BARK BEETLE POPULATION DYNAMICS-
STAND TREE MORTALITY SUBSYSTEM

Introduction

General Importance of Bark Beetles--

Bark beetles are one of the most important groups of forest insects in the United States. Although tree mortality due to these beetles varies considerably from year to year, the fact remains that these insects have tremendous potential for destruction. A breakdown of timber loss due to insects for 1952 showed bark beetles to be responsible for almost 90% of the total sawtimber mortality nationally (Graham and Knight, 1965). In California, bark beetles are considered to be the most important forest insect pests. The three most important species are the western pine beetle (*Dendroctonus brevicomis* Le Conte), the mountain pine beetle (*D. ponderosae* Hopkins), and the Jeffrey pine beetle (*D. jeffreyi* Hopkins). These beetles, along with the California flatheaded borer (*Melanophila californica* Van Dyke) and several other bark beetles, were responsible for a loss of 1676 million board feet of timber, valued at $23,235,000, in California in 1967.*

Literature Review--

Bark beetles are not necessarily primary attackers except during epidemics. They can usually be considered as secondaries or as symptoms of some other stress experienced by the tree. Stresses that predispose trees to attack by bark beetles include flooding, drought, lightning strikes, root disease, and photochemical air pollutants. Cobb *et al.* (1968) discuss the relationship of oxidant injury as well as other diseases to bark beetle infestations on ponderosa pine. It has been shown previously in the SBNF that as the severity of oxidant injury to ponderosa pine increased, the incidence of western pine beetle and mountain pine beetle infestation increased (Stark *et al.*, 1968). Oxidant injury, therefore, is an important agent predisposing pines to bark beetles attack, and can be considered in the same way as the other predisposing agents. This was further substantiated by an historical analysis of tree loss in one area in the SBNF (Lake Arrowhead) where there have been substantial increases in tree mortality due to bark beetles since 1951 (Wood, 1971). These tree mortality records will be used along with a pest damage inventory to evaluate the overall impact of bark beetles on a forest community stressed by oxidants. The effects of oxidant-weakened trees on the populations of bark beetles or flatheaded borers have not been studied previously. However, a study of ponderosa pine infested with western pine beetle at

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*California Department of Food and Agriculture, 31 July, 1968.

Blodgett Forest in the central Sierra Nevada has shown beetle populations to be higher in non-diseased trees in all respects (Dahlsten and Rowney, 1974). This study was a comparison of non-infected trees and those infected with the root pathogen, Verticicladiella wagenerii. Results are too preliminary to draw any conclusions about what this means in terms of either tree mortality or associated organisms, predators, and parasitoids.

Detailed studies of the population dynamics of the mountain pine beetle, the Jeffrey pine beetle, and the California flatheaded borer on ponderosa and Jeffrey pines in California have not been conducted. In addition, population sampling procedures have not been perfected for these species. The western pine beetle, however, has been studied in considerable detail, with early work summarized by Miller and Keen (1960). Recent studies have concentrated on the population dynamics of the western pine beetle and the development of population sampling techniques (Dahlsten et al., 1974; Stark and Dahlsten, 1970).

It is obvious that a forest community under the kind of stress, represented by high oxidant pollutant levels, will be predisposed to attack by the tree-killing beetle complex. So far, only trees most sensitive to pollutants have been studied in relation to the beetles that attack them. Bark beetles can have a tremendous effect on the age and species composition of a forest community. The beetles by killing certain tree species, actually hasten succession and therefore secondarily influence many other organisms and processes in the community. The removal of trees strongly influences the vegetation that follows. In addition, there will be changes in litter fall, soil moisture and structure, small mammal inhabitants, soil microarthropods, litter decay rates, and regeneration. The rates of change, however, may be ameliorated by the influence of oxidant-injured trees on beetle populations. This interaction will have to be characterized in order to model and eventually predict the influence and rates of change in forest communities affected by photochemical oxidant air pollutants.

Research Objectives

The main objectives of this subproject are to characterize the role of tree-killing beetles in stands predisposed by photochemical air pollutants. The relationship of the beetles to other components in the ecosystem is shown in Figure 53. Specific objectives are as follows:

1) To determine the degree of susceptibility of oxidant-injured ponderosa pine to the western pine beetle and the mountain pine beetle, and of Jeffrey pine to the Jeffrey pine beetle and the California flatheaded borer.

2) To investigate the influence of oxidant-injured pine trees on the success and productivity of broods of the four beetle species to be studied.

3) To study the direct and indirect influence of photochemical oxidant pollutants on the biology of the four tree-killing beetles,

with particular reference to insect associates, parasitoids, and predators.

4) To develop life tables for the four beetles by oxidant injury categories and, based on these tables, to develop predictive models of beetle activity with reference to stand type and pine oxidant-injury level.

5) To determine the biological impact and relative importance of each of the beetle species in forest communities and what influence they have on stand change and forest succession.

Methods and Materials

Field Sampling Techniques for Bark Beetles--

Western pine beetle--Sampling procedures used in this study have been developed within the past ten years (Stark and Dahlsten, 1970; Dahlsten *et al*., 1974). Details of the sampling procedures including laboratory methods, data forms, and analytical procedures are given by Dahlsten (1974).

The ideal situation is to locate four infested trees in each oxidant-injury category for each beetle generation. We used three oxidant-injury classes as defined by the oxidant-injury rating score of Miller (1973) (Table 24). Therefore, twelve trees were sampled each generation from 1973-74. This was reduced to six for 1975 (see below). Trees are often green and have not faded, so beetle-produced frass (boring dust) or pitch tubes were used to find infested trees. Local personnel of the State Division of Forestry and the U.S. Forest Service aided in the search for trees. Once trees were found, they were given an oxidant injury rating, and other statistics such as height and diameter were recorded. Trees with mixed broods (more than one species of bark beetle present) were not selected. The mountain pine beetle and the western pine beetle are commonly found infesting the same tree.

The various sampling procedures, the data form identification, and the types of information recorded are shown in Figure 53. The basic sample unit consisted of paired 88 cm^2 discs cut with a gasoline-powered Drillgine saw. Samples were taken at 1.5 m intervals along the length of the infestation. A summary of the four procedures follows:

1) Egg discs. Paired discs were cut at 3.0 m intervals, (it is not necessary to take these discs at 1.5 m intervals, so every other sample height is skipped). These discs were taken only once per generation and were used to evaluate attacks, egg density, and egg mortality.

2) X-ray discs. Paired discs were cut at 1.5 m intervals, returned to the laboratory, x-rayed, and then placed in rearing cartons. During the first generation, discs were cut twice: the first time occurred when the beetles reached, at most, the third instar of larval development; and the second time occurred just prior to, or immediately after, pupation. The second generation was treated differently since the beetles

overwintered in this generation. Discs were taken three times: once at the third instar stage, once before winter, and then again in the spring of the following year. Developed x-rays were interpreted for beetle stage, parasitoids, predators, and miscellaneous insects. The abundance of each of these inclusion types was recorded.

3) Rearing. Each x-ray disc was placed in a separate ice cream container to which a vial was attached and placed through the lid. All insects were reared from the bark discs, collected, and identified. Approximately 75 species were reared from these samples. Discs were kep in rearing nine to twelve months.

4) Sticky carton. The interiors of ice cream containers were lined with a sticky substance (Stikem Special) to prevent insects from boring out. The containers were placed on trees in pairs at 1.5 m intervals when the last x-ray discs were taken. These cartons cover an area of 88 cm^2. Cartons were put up once during the first generation and removed for analysis only after it was determined that all insects had emerged from the study trees. Cartons were put up and removed twice in the second generation, once before and once after winter. The sticky cartons were used as a comparison to the laboratory-reared samples, since rearing conditions influence the western pine beetle as well as a number of the other insects associated with it.

During the 1975 field season only six ponderosa pine infested with *D. brevicomis* were sampled for each of the two annual beetle generations. This is half the number of trees normally sampled per generation. Phloem thickness was recorded for each sample tree. In addition, trees were examined for evidence of root pathogens, but no evidence of disease was found.

Mountain pine beetle and Jeffrey pine beetle--Studies on these two beetles were initiated in 1974 to develop sampling procedures and to rear and identify associated insect species.

Infested trees in which broods had completed development were selected whenever possible. Mixed broods were avoided, but bark beetles (*Ips* spp.) or California flatheaded borers were found often in portions of the sample trees. Six *D. jeffreyi*-infested Jeffrey pines from the Big Bear and Heart Bar areas and five *D. ponderosae*-infested ponderosa pines from the Lake Arrowhead area were used to determine sample size, cost, and efficiency. Bolts were taken from one tree of each species for rearing. Sample bolts were taken from the top, middle, and bottom of each infested pine species. Broods in both trees were in the late pupal stage, and all rearing was done outside at Lake Arrowhead. Emerging insects were trapped in KAAD (a preservative for insects) and collections were made on a weekly basis from 26 July through 14 November, 1974.

Each tree to be sampled was felled, examined for mixed broods, and measured for standard tree and infestation characteristics. Paired samples were taken from points 1.5 m above the base of infestation, 1.5 m below the top of the infestation, and from the mid-point between the two. The samples were sections of bark 60 cm long by one half the circumference of the bole.

Vegetation plot surveys--The 19 permanent vegetation plots were surveyed in June and November of each year for tree mortality. The insects responsible for the death of each tree were recorded.

Laboratory Analysis--

Western pine beetle--Dissection of egg discs, x-ray interpretation, and collection and identification of all insects from rearing cartons and sticky cartons was done in the laboratory. The information was punched on cards, verified, corrected, and put into the information system (Fig. 53).

Mountain pine beetle and Jeffrey pine beetle--Analysis of each sample consisted of placing an acetate overlay upon which five nested samples (rectangles of 1000 cm^2, 500 cm^2, 250 cm^2, 100 cm^2, and a circle 100 cm^2) were drawn. Parameters measured included: number of attacks, adult gallery length, number of larval mines, pupal cells, emergence holes, and in some cases the number of egg niches and Coeloides (a parasitoid) cocoons. These data were punched onto cards for analysis, but data from this study were not put into the larger information system.

Results and Discussion

Preliminary Analyses of Bark Beetle Population--

Wester pine beetle--Only the egg data for 1973 and 1974 were available for summarization (Table 25). The trends indicated by the egg data, however, were fairly definite. Other interesting influences of oxidant air pollutants on other aspects of western pine beetle biology are anticipated. Since populations of western pine beetle have been studied for the past ten years at Blodgett Experimental Forest (Stark and Dahlsten, 1970; Dahlsten *et al*., 1974), there is a base of information available to compare with the SBNF populations. These comparisons will be interesting, as many of the ponderosa pines at Blodgett have been stressed by a root pathogen, *Verticicladiella wagenerii*; but there is little, if any, oxidant air pollutant injury to the trees.

In the SBNF, the mean attack rates of beetles were highest in the first generation in both years (Table 25). A similar trend was noted at Blodgett Forest, but the differences are greatly exaggerated in the SBNF. The mean attack rates in the first generation of 1973, (hereafter referred to 1973-1) were higher (2.57 and 2.49/sample disc) than any of the previously recorded highs at Blodgett (1.82/sample disc). Not enough generations have been studied to explain this phenomenon.

Mean attack rates were more variable in the SBNF, which may be an effect of air pollutants on the trees. Attack rates tended to be higher in the Class III trees ("slight" to "no visible symptoms") except in the 1973-1 generation. However, if that generation was part of an epidemic outbreak, it could explain the breakdown of any behavior pattern. For example, vigorous trees, or trees not predisposed by some other factor, are often killed by beetles during epidemic outbreaks.

Another valuable attribute for evaluating bark beetle populations (Objective 2) is the mean number of eggs per centimeter of gallery length. Results were extremely variable, and no consistent trend could be found (Table). The values tended to be higher in the second generation in both years. A similar trend was noted at Blodgett (Dahlsten et al., 1974). Again the data from the SBNF is much more variable than that from Blodgett. The values from five second generations at Blodgett ranged from 1.46 to 1.94 eggs/cm gallery length, and for four first generations from 1.32 to 1.54 eggs/cm gallery length. Values consistently less than 1.0 were recorded in the SBNF. The highest value, 1.37, was recorded on severely injured trees in the 1974-2 generation, but results from other generations were too variable to draw any conclusions.

The percentage of hatched eggs per sample disc can often be used as an index of egg mortality, which is essential for both estimates of brood productivity (Objective 2) and development of meaningful life tables (Objective 4). The egg discs can and must be taken well after oviposition occurs to insure that all ecolosion (hatching) has occurred. Estimates of egg mortality at Blodgett vary between 15 and 25 percent. Again, the data from the SBNF are more variable (Table 25). There was a tendency for the percentage of eggs hatched to be lower in the less severely injured trees. Since the percentage of eggs hatched is used as an indicator of egg mortality, there is a possibility that oxidant-injured trees increase egg mortality primarily or secondarily. Work on this facet of the egg data will be expanded in the future (Objective 3).

The following is the status of the data capture routines for the western pine beetle population study:

1) A system for capturing egg data has been developed and is operational. This system consists of computer routines which capture egg data (EGG) and which analyze it (EGGSUMS and STATPAK). Field data has been summarized for 1973 and 1974 (Table 25).

2) A system for capturing x-ray data has been developed and is also operational. This system consists of computer routines which capture x-ray data (XRAY) and which analyze it (XRAYSUMS and STATPAK).

3) Computer routines which capture tree data, sticky carton data, rearing data and tree-bug data (BTREE, STIK, REAR, and TBUG) have been programmed and debugged but are not fully operational.

Mountain pine beetle and Jeffrey pine beetle--Sampling procedures were not available for either the mountain pine beetle or the Jeffrey pine beetle. The first step was to determine sample size. Preliminary summaries and statistics for number of attacks and gallery length have been completed for both species (Tables 26 and 27). Results have been analyzed statistically and the data suggests that a 500 cm^2 rectangle would be suitable.

Counts of larval mines and pupal cells of D. jeffreyi were complicated by the feeding of the California flatheaded borer which was present to varying degrees in all samples. Estimates of the proportion of the host sample utilized by the flathead larvae were recorded and will be used to evaluate interspecific competition. Field observations indicated that the flatheaded borer may be an important component in the forest communities of southern California, particularly in Jeffrey pine.

Mountain pine beetle trees were also difficult to locate and broods were usually mixed with those of the western pine beetle. There was evidence that ponderosa pines had been killed by mountain pine beetles, but currently infested trees were rarely located in 1974. This suggested an important interaction with western pine beetle populations; however, it appears that the most important factors in extensive pine mortality are the western pine beetle and the flatheaded borer. Further studies should concentrate on these beetles, and not the mountain pine beetle or the Jeffrey pine beetle.

All insects reared from the sample bolts to determine the associates of the mountain pine beetle and the Jeffrey pine beetle have been preserved, identified, and counted (Tables 28 and 29). Future analyses of rearings for both species will include the distributions of each insect through time and by height on the tree. A knowledge of the associate complex for each species is necessary for evaluating the effects of oxidant-injured pines on beetle populations either directly or indirectly through the effects of parasitoids, predators, and competitors. The species lists compiled thus far are consistent with the present knowledge of bark beetle associate complexes (Dahlsten, 1971; Dahlsten and Stephen, 1974).

Vegetation plots--Trees killed by insects on the 18 vegetation plots are summarized and the mean oxidant injury score is given in Table 30. The most common cause of mortality in ponderosa pine was the western pine beetle, followed by mixed populations of western and mountain pine beetles.

The most common cause of Jeffrey pine mortality was the Jeffrey pine beetle. The mean oxidant injury scores for those trees killed by the Jeffrey and western pine beetles were the lowest for their respective host trees. This may explain why these two beetles are the most common killers of ponderosa and Jeffrey pine in southern California as they are more successful on the more seriously weakened trees. This is only a trend, and a more extensive pest damage inventory will need to be undertaken to resolve this question.

Conclusion

Western Pine Beetle--

Based on comparisons with population studies of the western pine beetle in other regions of California, it appears that oxidant-stressed trees influence several aspects of western pine beetle biology. There is a greater difference in attack rates between generations than occurs in other areas of California, and this indicates that oxidant-stressed trees are killed by fewer beetles than non-stressed trees. All population variables measured are more variable and erratic in southern California, which may indicate that the interaction of smog-weakened trees and western pine beetles is unique and that this relationship is more direct than previously thought. A survey of the vegetation plots showed the western pine beetle to be the most common killer of ponderosa pine. In addition, this beetle appears to attack the more seriously oxidant-damaged trees.

Mountain Pine Beetle and Jeffrey Pine Beetle--

On the basis of a limited sampling study of the mountain pine beetle in ponderosa pine, and the Jeffrey pine beetle in Jeffrey pine, the most efficient sample unit was found to be 500 cm^2. The mountain pine beetle was not as common in dead ponderosa pine on the vegetation plots as the western pine beetle. The Jeffrey pine beetle was the most common killer of Jeffrey pine.

Priorities for Future Research--

It appears from the preliminary analysis of these data that population sampling of the western pine beetle and the Jeffrey pine beetle should be continued. In addition, an extensive survey of ponderosa and Jeffrey pine mortality should be undertaken. During the 1976-77 year, emphasis will be put on the analysis of the population data. In addition tree mortality records will be examined.

TABLE 24. WESTERN PINE BEETLE-INFESTED PONDEROSA PINES RANKED BY OXIDANT DAMAGE CLASSES AND BEETLE GENERATIONS, 1973-1975.

D. brevicomis generation	Damage Class Very severe (1-8)	Severe (9-14)	Moderate (15-21)	Slight (22-28)	Very slight (29-35)	No visible symptoms (36 +)
1973-1	0	0	2	6	3	1
1973-2	3	3	4	0	0	2
1974-1	2	3	0	7	0	0
1974-2	5	4	1	2	0	0
1975-1	2	2	0	2	0	0
1975-2	2	0	2	0	1	1
Totals	14	12	9	17	4	4

TABLE 25. WESTERN PINE BEETLE EGG DISSECTION DATA GROUPED BY GENERATION AND OXIDANT INJURY CLASS*/ EPA, SAN BERNARDINO AIR POLLUTANT STUDY - 1973-1974.

No. Samples or Means	1973						1974					
Oxidant injury	1st. Generation			2nd. Generation			1st. Generation			2nd Generation		
class	I	II	III	I	II	III	I	II	III	I	II	III
No. trees	0	8	4	6	4	2	5	7	0	10	2	0
No. discs		88	44	60	36	20	48	98		104	13	
Disc/galleries		82	43	57	34	19	46	95		92	13	
Attacks/disc with galleries		2.57	2.49	0.78	0.89	1.69	1.84	2.23		0.87	0.89	
Gallery length (cm)/ disc with galleries		69.80	71.48	37.46	36.97	40.18	63.04	47.45		32.27	35.65	
No. eggs/disc with galleries		63.70	60.76	31.83	43.46	37.54	41.70	54.55		43.77	51.25	
No. eggs/cm gallery		0.89	0.88	0.85	1.17	0.90	0.66	0.82		1.37	1.10	
% hatched eggs		85.18	80.73	68.92	70.46	67.12	84.80	83.39		71.90	45.20	

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*/ Trees classed according to oxidant injury score (Miller, 1973); i.e.,

Class I	Score 1-14	Very severe to severe injury
Class II	Score 15-28	Moderoate to slight injury
Class III	Score 29+	Very slight to no visible symptoms of injury

TABLE 26. PRELIMINARY ANALYSIS OF NUMBER OF ATTACKS AND GALLERY LENGTH FOR THE MOUNTAIN PINE BEETLE FROM VARYING BARK SAMPLE SIZES (DATA CONVERTED TO 1000 cm^2 FOR COMPARISON). EPA, SAN BERNARDINO AIR POLLUTANT STUDY, 1974.

Location of sample	Sample size (cm^2)	Number of Attacks			Gallery Length		
		Number of samples	Mean	Standard deviation	Number of samples	Mean (cm)	Standard deviation (cm)
Base of infestation	100	10	3.00	6.75	10	246.0	182.9
	100	10	4.00	9.66	10	278.0	198.3
	250	10	3.60	3.98	10	243.6	155.9
	500	10	3.00	3.43	10	230.8	123.5
	1000	10	3.00	2.71	10	195.5	95.1
Middle of infestation	100	9	5.56	5.27	10	230.0	114.8
	100	9	5.56	5.27	10	266.0	130.8
	250	9	4.00	3.46	10	253.2	120.4
	500	9	2.89	1.76	10	243.8	87.0
	1000	8	3.00	2.45	9	216.8	78.2
Top of infestation	100	10	0	0	10	142.0	99.4
	100	10	0	0	10	160.0	113.2
	250	10	0	0	10	141.6	80.8
	500	8	1.00	1.51	8	159.8	93.9
	1000	6	1.50	1.97	5	147.8	129.3

TABLE 27. PRELIMINARY ANALYSIS OF NUMBER OF ATTACKS AND GALLERY LENGTH FOR THE JEFFREY PINE BEETLE FROM VARYING BARK SAMPLE SIZES (DATA CONVERTED TO 1000 cm^2 FOR COMPARISON), EPA, SAN BERNARDINO AIR POLLUTANT STUDY, 1974.

		Number of Attacks			Gallery Length		
Location of sample	Sample size (cm^2)	Number of samples	Mean	Standard deviation	Number of samples	Mean (cm)	Standard deviation (cm)
Base of infestation	100	12	3.33	4.92	12	146.7	89.98
	100	12	3.33	4.92	12	156.7	96.42
	250	12	2.00	2.09	12	144.3	63.04
	500	12	3.33	2.31	12	144.5	56.90
	1000	12	2.83	1.58	12	136.7	52.81
Middle of infestation	100	12	3.33	6.51	12	135.8	107.7
	100	12	3.33	6.51	12	141.7	112.4
	250	12	2.67	4.29	12	133.3	78.32
	500	12	2.83	3.01	12	117.7	67.30
	1000	12	2.91	2.57	12	112.8	57.05
Top of infestation	100	12	2.50	4.52	12	71.67	59.52
	100	12	4.17	5.15	12	89.17	69.86
	250	12	2.33	3.17	12	82.00	62.93
	500	12	2.67	2.87	12	80.00	59.60
	1000	12	2.42	2.35	12	84.25	52.47

TABLE 28. TOTAL ARTHROPODS REARED FROM PONDEROSA PINE BOLTS INFESTED WITH MOUNTAIN PINE BEETLE FROM THREE HEIGHTS IN 1974, SAN BERNARDINO.

Arachnida	
Araneae	3
Pseudoscorpionida	
Chernetidae	68
Insecta	
Hemiptera	
Anthocoridae	
Lyctocoris sp.	2
Species #2	1
Unknown nymphs	8
Neuroptera	
Inocelliidae	
Inocellia sp.	14
Raphidiidae	
Agulla sp.	52
Chrysopidae	
Species #1	1
Unknown larvae	2
Coleoptera	
Histeridae	
Plegaderus sp.	338
Platysoma sp.	10
larva #1	18
larva #2	2
Scaphidiidae	
Species #1	1
Staphylinidae	
Nudobius sp.	4
Species #2	1
Dermestidae	
Species #1	2
Ostomidae	
Temnochila sp.	119
Tenebroides sp.	4
Cleridae	
Enoclerus sp.	171
Species #4	4
Rhizophagidae	
Rhizophagus	2
Cryptophagidae	
Salebius sp.	3
Nitidulidae	
Species #1	1
Lathridiidae	
Corticaria sp.	12
Colydiidae	
Lasconotus sp.	10
Aulonium sp.	138
Othniidae	
Othnius sp.	28
Tenebrionidae	
Corticeus sp.	38
Melandryidae	
Rushia sp.	127
Bostrichidae	
Species #1	14
Curculionidae	
Cossonus sp.	293
Lechriops sp.	1
Scolytidae	
Dendroctonus valens Lec.	1
D. brevicomis	11
Pityokteines sp.	307
Gnathotrichus sp.	32
Unknown larvae	
Species #3	256
Lepidoptera	
Unknown species	2
Diptera	
Ceratopogonidae	
Species #1	233
Sciaridae	
Species #1	21
Scatopsidae	
Species #1	1
Cecidomyiidae	
Species #1	5
Stratiomyidae	
Zabrachia sp.	289
Scenopinidae	
Belosta sp.	27
Empididae	
Drapetis sp.	11
Dolichopodidae	
Medetera sp.	7
Species #2	2
Phoridae	
Species #1	51

TABLE 28. (CONTINUED)

Diptera (continued)	
Londraeidae	
Species #1	33
Milichiidae	
Species #1	22
Drosophilidae	
Species #1	8
Sarcophagidae	
Species #1	2
Unknown larvae	
Species #1	116
Hymenoptera	
Braconidae	
Species #1	2
Species #2	1
Encyrtidae	
Species #1	8
Species #4	2
Species #6	1
Torymidae	
Roptrocerus sp.	81
Pteromalidae	
Species #1	5
Bethylidae	
Species #1	1
Formicidae	
Species #2	1
Sphecidae	
Pemphredon sp.	1

TABLE 29. TOTAL ARTHROPODS REARED FROM JEFFREY PINE BOLTS INFESTED WITH JEFFREY PINE BEETLE FROM THREE HEIGHTS IN 1974, SAN BERNARDINO.

Arachnida	
Araneae	156
Pseudoscoptionida	
Chernetidae	31
Insecta	
Neuroptera	
Inocelliidae	
Inocellia sp.	3
Raphidiidae	
Agulla sp.	2
Coleoptera	
Scaphidiidae	
Species #1	1
Staphylinidae	
Species #1	1
Species #2	1
Species #4	1
larvae	25
Clambidae	
1 species	1
Dermestidae	
Megatoma sp.	1
larvae #1	13
Malachiidae	
Species #1	1
Ostomidae	
Temnochila sp.	44
Cleridae	
Enoclerus sp.	57
Species #3	15
Buprestidae	
Larvae #1	12
Rhizophagidae	
Rhizophagus sp.	1
Cryptophagidae	
Salebius sp.	8
Nitidulidae	
Species #1	2
Colydiidae	
Lasconotus sp.	3
Aulonium sp.	1
Othniidae	
Othnius sp.	21
Tenebrionidae	
Larvae #1	26
Curculionidae	
Cossonus sp.	1
Scolytidae	
Ips pini Lanier	1
Ips latidens (LeC)	2
Pityokteines ornatus (Swaine)	3
Gnathotrichus sp.	189
Unknown Larvae #1	1
Lepidoptera	
Larva #1	1
Species #2	1
Diptera	
Ceratopogonidae	
Species #1	2,993
Mycetophilidae	
Species #1	1
Sciaridae	
Species #1	40
Scatopsidae	
Species #1	1
Cecidomyiidae	7
Stratiomyidae	
Zabrachia sp.	28
Scenopinidae	
Belosta sp.	2
Empididae	
Drapetis sp.	9
Dolichopodidae	
Medetera sp.	7
Species #2	1
Phoridae	
Species #1	224
Milichiidae	
Species #1	23
Unknown larvae	
Species #1	91
Species #2	98
Species #4	27

TABLE 29. (CONTINUED)

Hymenoptera	
Braconidae	
Species #1	12
Encyrtidae	
Species #1	10
Species #2	1
Species #3	10
Species #4	2
Species #5	1
Avetienella sp.	3
Eurytomidae	
Eurytoma sp.	2
Diapriidae	
Species #1	1
Formicidae	
Species #1	24
Colletidae	
Species #1	1

TABLE 30. PRELIMINARY SUMMARY OF FINAL SMOG DAMAGE RATINGS[*] FOR PINES KILLED BY INSECTS ON ESTABLISHED VEGETATION PLOTS, 1973-1975.

Tree Species[+]	Insect species[‡]	Number of trees	Oxidant injury score			
			Mean	SD	SE	Range
PP	D.b.	17	9.9	6.3	1.5	1-21
PP	D.p.	7	10.4	6.3	2.4	6-25
PP	Mixed (D.b. Broods +D.p.)	8	11.8	8.6	3.0	1-30
PP	Ips & M.c. (combined)	5	15.2	10.0	4.5	2-32
JP	D.j.	7	11.6	6.7	2.5	3-19
JP	Mixed (D.j. Broods +Ips)	4	13.0	8.2	4.1	4-23

[*] All Scores given by P. Miller except those from 1973.

[+] PP = ponderosa pine; JP = Jeffrey pine

[‡] D.b. = *Dendroctonus brevicomis*; D.p. = *D. ponderosa*; D.j. = *D. jeffreyi* Ips = *Ips sp.*; M.c. = *Melanophila californica*.

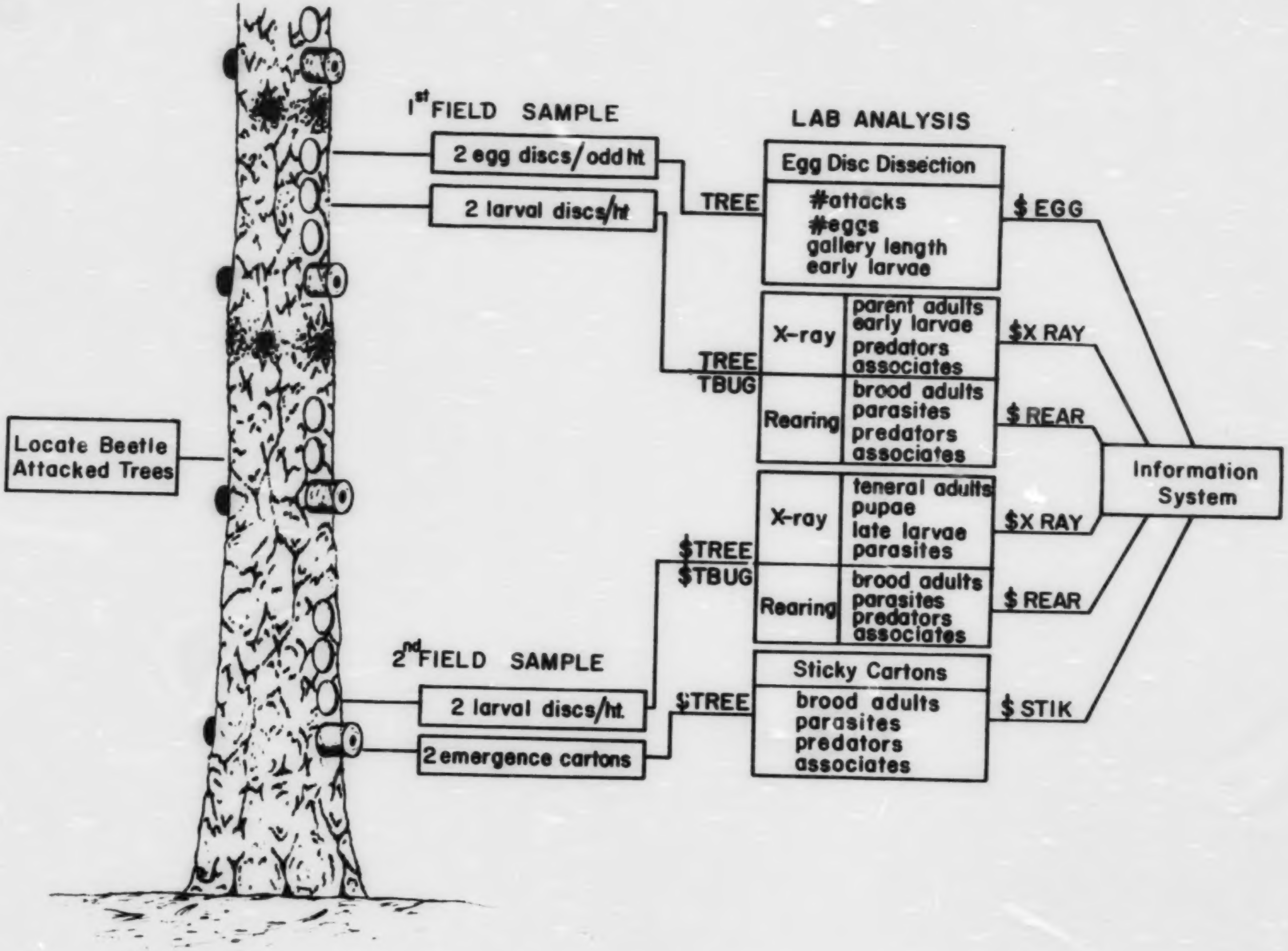

1st FIELD SAMPLE
2 egg discs/odd ht
2 larval discs/ht
2nd FIELD SAMPLE
2 larval discs/ht.
2 emergence cartons
Locate Beetle Attacked Trees
TREE
TREE
TBUG
$TREE
$TBUG
$TREE
LAB ANALYSIS
Egg Disc Dissection
#attacks
#eggs
gallery length
early larvae
X-ray
parent adults
early larvae
predators
associates
Rearing
brood adults
parasites
predators
associates
X-ray
teneral adults
pupae
late larvae
parasites
Rearing
brood adults
parasites
predators
associates
Sticky Cartons
brood adults
parasites
predators
associates
$ EGG
$X RAY
$ REAR
$X RAY
$ REAR
$ STIK
Information System

Figure 53. Graphic summary of the population sampling procedures used for the western pine beetle, showing data sets and the type of information included for the San Bernardino study.

ROOT PATHOGEN DYNAMICS AND STAND MORTALITY

Introduction

Pathogens have a subtle, but often profound influence on a forest ecosystem. Their activity may affect the rate and even the direction of successional changes (Baxter, 1952; Smith, 1970), the occurrence of plant species, and the overall productivity of the plant community. Thus, fundamental information on the effects of photochemical air pollutants on the activities of forest pathogens is essential in developing models to predict long-term effects of pollutants on the forest ecosystem as a whole.

There are many potential pathogens in any forest, including viruses, bacteria, fungi, and higher plant parasites such as the mistletoes. Some may infect the whole plant, whereas others may be limited to foliage, the branches, stems, or roots. Many pathogens may have little effect upon the forest; however, others may have a devastating effect. To determine the effects of air pollutants on all forest pathogens is clearly beyond our practical capabilities. Thus, to limit the scope of the study while developing an initial estimate of the effects of pollutants, we have chosen two approaches.

First, we attempted to develop a general overview of the potential effects of air pollutants on disease incidence and severity through a disease survey. All trees on 18 permanent study sites established across the oxidant air pollutant gradients in the SBNF were examined periodically. Each tree was examined for diseases of roots, stems, branches, and foliage. Rates of increase or decrease in the occurrence of disease were determined through periodic examinations (at least once every two years) for the duration of the study. Data were analyzed to determine the relationship between disease incidence and oxidant air pollutant levels.

Second, we conducted intensive studies of selected pathogens to determine the effects of oxidant air pollutants on their occurrence and on the various stages of their life history. To date, studies have been initiated on one specific pathogen, *Fomes annosus* (Fr.) Cke. The selection of this pathogen was based on (1) the known or potential importance of the pathogen in the plant community under investigation; (2) the potential importance of the pathogen in the plant succession model; (3) interactions with other components of the system being studied; and (4) present knowledge of the pathogen, the facility with which it can be studied, and potential application of the results.

F. annosus is usually considered to be one of the most destructive root pathogens in conifer forests of California (Bega and Smith, 1966).

Hosts include ponderosa and Jeffrey pine, both of which are adversely affected by oxidant air pollutants. F. annosus has been found to cause damage to these species in the San Bernardino Mountains. However, the effects that oxidant air pollutants may have on susceptibility of ponderosa and Jeffrey pine to infection and colonization by the fungus are unknown. Also the ability of the fungus to live, proliferate, and cause disease in an environment with oxidant air pollution is unknown.

The following model (Fig. 54) indicates areas where oxidant air pollutants probably have direct and indirect effects on disease development by the fungus.

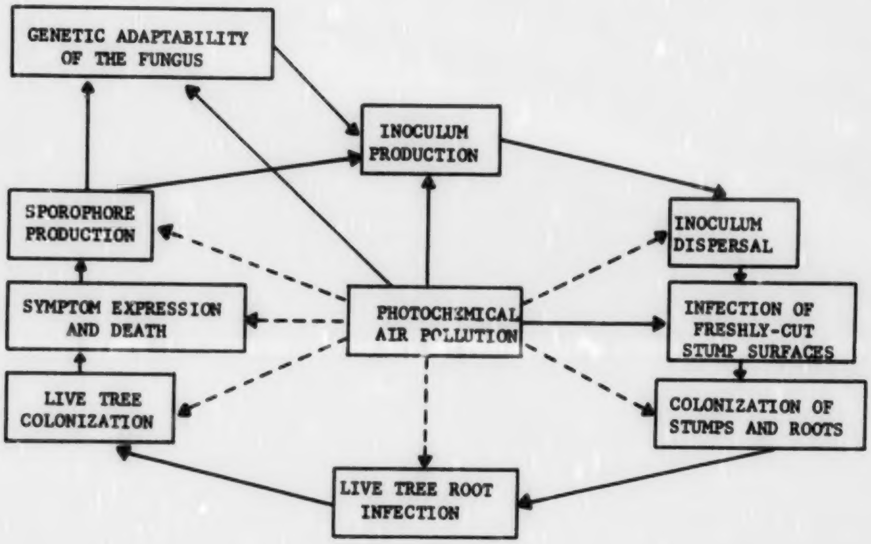

GENETIC ADAPTABILITY OF THE FUNGUS
INOCULUM PRODUCTION
SPOROPHORE PRODUCTION
INOCULUM DISPERSAL
SYMPTOM EXPRESSION AND DEATH
PHOTOCHEMICAL AIR POLLUTION
INFECTION OF FRESHLY-CUT STUMP SURFACES
LIVE TREE COLONIZATION
COLONIZATION OF STUMPS AND ROOTS
LIVE TREE ROOT INFECTION

Figure 54. Conceptual model of oxidant effects on the Fomes annosus root disease.

This study was established primarily to determine the effects of pollutants on the life history of F. annosus as outlined above. Field studies were used as much as possible, since results would be more applicable to actual conditions in the forest. However, certain controlled-environment investigations were necessary to monitor ozone concentration and other environmental factors closely, and to properly establish cause and effect relationships. Study sites were chosen based on species location and presence of oxidant air pollutant injury. Ponderosa and Jeffrey pines were the two tree species used in the study.

Methods and Materials

Rates of Local Spread and Tree Mortality--

Naturally occurring *F. annosus* infection centers, primarily in ponderosa and Jeffrey pines, were plotted and exmained annually to determine the rate at which the fungus apparently moves through roots to infect adjacent trees, and the rate of tree mortality in these centers. Wherever feasible, these plots were located along the air pollution gradient. Data were recorded on the tree species, diameter (BH), height, crown class, pollution damage, and any symptoms of *F. annosus*, insect, or other pathogen activity.

Susceptibility of Roots of Young Sawtimber Trees--

To compare *F. annosus* susceptibility of existing trees showing light and severe oxidant air pollution injury, inoculation of roots with the fungus was necessary. The 42 trees (ponderosa and Jeffrey pine) used in this study were mostly codominant and averaged 38 cm DBH. Two roots of each tree were inoculated and analyzed for infection and colonization at the end of 6 and 12 months.

Tree Seedling Susceptibility--

A controlled environment experiment was undertaken to determine the susceptibility to *F. annosus* of ponderosa and Jeffrey pine seedlings fumigated at ozone concentrations of 431.2 and 882.0 $\mu g/m^3$. A suitable number of noninoculated and nonfumigated controls were included. Seedlings used in this experiment were grown initially in activated charcoal-filtered greenhouses and, therefore, were not exposed to ambient air pollutants.

Susceptibility of Freshly-Cut Stumps--

F. annosus often spreads to new areas by infecting the surface of freshly cut stumps. Infection centers are established when the fungus moves from infected stumps to adjacent live trees through root grafts and contacts. To investigate this type of infection, ponderosa and Jeffrey pine trees in each of two groups--"none" to "slight," or "severe" to "very severe" oxidant injury--were cut and their stumps inoculated with a conidial suspension of the fungus.

Laboratory Decay Studies--

F. annosus generally causes decay of the wood of infected trees. Thus, studies evaluating the decay capacities of the fungus on wood from air pollution-injured trees were initiated. Wood from ponderosa pine trees, cut for the stump inoculations, was used in a standard soil-block decay test (American Society for Testing and Materials, 1973) to determine decay rates expressed as weight loss over time. In addition to *F. annosus*, *Poria monticola* Murr. and *Polyporus versicolor* (L.) Fr., two standard decay fungi, were used in this study.

Cultural Studies--

Because *F. annosus* as well as its hosts is exposed to air pollutants in the San Bernardino Mountains, studies are being conducted to determine the direct effects of ozone on the fungus. Effects on growth, production, and germination of reproductive spores, and genetic adaptability of the fungus are being studied. This entails fumigating fungus cultures in specially constructed growth chambers with various levels of ozone.

Miscellaneous Studies--

A number of additional studies have been initiated recently. One is designed to evaluate inoculum concentration of _F. annosus_ by sampling the spore load at a number of sites throughout the San Bernardino Mountains. Such evaluations will help determine the effects of oxidants on sporulation and the relative hazard of _F. annosus_ at this time.

Also, studies were begun in 1976 to determine by seedling inoculations whether ozone can influence virulence of _F. annosus_. Such an evaluation is potentially important in assessing overall oxidant effects on the pathogen.

Results and Discussion

Rates of Local Spread and Tree Mortality--

Thus far, ten plots have been established and more (up to 21) were planned for 1976. These plots will be studied for the duration of the project. To date, data has been taken twice on the initial plots, but at least another year will be needed to analyze for trends in rates.

Susceptibility of Roots of Young Sawtimber Trees--

All data have now been collected from the first series of inoculations, and the results are sumarized in Table 31. Regression analyses of pollutant damage vs. total root colonization indicated no significance at P=0.05 for either ponderosa or Jeffrey pine.

Proximal movement of _F. annosus_ (toward the tree trunk) is probably a better indicator of host susceptibility, especially when compared to that which occurs in severed roots. A regression analysis indicated that the relationship between pollutant damage and proximal colonization for ponderosa pine was significant at P=0.01; for Jeffrey pine, the relationship was not significant. It should be pointed out, however, that numbers of Jeffrey pine inoculated were severely restricted, none of the Jeffrey pine was severely damaged by pollutants, and the test was confounded by moderate-severe damage by a needle miner.

Another root inoculation trial involving 20 ponderosa pines was established to confirm the results indicated Table and to test _F. annosus_ isolate variability. Also, an additional inoculation trial of 62 trees was initiated to test variability of different pathogen isolates in an area where oxidant air pollution is not an influencing factor.

Tree Seedling Susceptibility--

The percentage of infection of fumigated seedlings was greater than that of nonfumigated seedlings (Table 32). A simple comparison between all ozone and control treatments showed statistically significant differences in colonization among treatments for ponderosa and Jeffrey pine

TABLE 31. INFECTION AND COLONIZATION BY *FOMES ANNOSUS* OF OXIDANT INJURED JEFFREY AND PONDEROSA PINE TREES IN NATURAL STANDS

Tree species	Pollution injury	Infection (%)	Average colonization* (cm)
Jeffrey pine	None	56.3	36.3
Jeffrey pine	Slight	53.3	23.1
Jeffrey pine	Moderate	41.7	21.6
Ponderosa pine	Slight	43.7	14.7
Ponderosa pine	Moderate	75.0	18.2
Ponderosa pine	Severe	45.0	21.6

*Colonization includes distal and proximal movement by the fungus. Average values include only those roots which became infected.

at the 5% and 25% levels, respectively.

If the data were considered according to the time of inoculation with respect to length of ozone fumigation, it was found that the rate of colonization of host tissue was also significantly greater at the highest ozone doses.

For example, in the first inoculation schedule, one-third (8) of all seedlings in each of eight fumigation cubicles were inoculated on June 21. Fumigation began several days later and continued until August 23 (day 58), when these seedlings were removed for confirmation of infection and measurement of the fungal invasion above and below (cm) the inoculation point. A zero was given when no infection occurred. The total doses were 3.0 and 6.1 X 10^5 $\mu g/m^3$ -hr, respectively, and were administered at concentrations of 431 and 882 $\mu g/m^3$, respectively. Two control groups of 8 seedlings, each of which had been maintained in carbon-filtered air in identical cubicles, were removed for evaluation at the same time. An analysis of variance shows that 95 times out of 100 there were no differences in disease development between control and fumigated seedlings as measured by movement of the fungus in root crown tissues. The ozone injury scores at 3.0 X 10^5 $\mu g/m^3$ -hrs, determined by the same method as in Fig. 39, were 4.0 and 6.3 for ponderosa, 10.6 and 11.1 for Jeffrey pine.

In the second inoculation schedule, 8 additional seedlings in each fumigation cubicle were inoculated on August 8, after 37 days of ozone

TABLE 32. INFECTION OF OZONE FUMIGATED AND UNFUMIGATED JEFFREY AND PONDEROSA PINE SEEDLINGS BY *FOMES ANNOSUS*

Pine species	No. seedlings	Fumigation conc. (O_3) ($\mu g/m^3$)	Infection (%)
Jeffrey	32	0.	53.1
Jeffrey	16	431.2*	75.0
Jeffrey	16	882.0	81.0
Ponderosa	32	0.	62.0
Ponderosa	16	431.2	81.0
Ponderosa	16	882.0	75.0

*Seedlings at each concentration were exposed for a period ranging between 58 and 87 days.

fumigation or filtered-air treatment. Fumigation was continued for an additional 50 days at the same concentrations, after which seedlings were removed and disease development was determined. The total ozone doses were 4.5 and 9.2 X 10^5 $\mu g/m^3$-hr. In Table 33, a definite trend toward increased disease development is indicated at the highest ozone dose. The results show that 95 times out of 100, the largest total dose resulted in greater disease development when the combined ponderosa and Jeffrey pine populations from the 9.2 X 10^5 $\mu g/m^3$-hr dose were compared with one control group using Duncan's multiple range test. Needle injury scores were very similar at both doses and for both species.

The 8 seedlings remaining in each cubicle were not inoculated. Each tree was observed periodically to compare ozone injury scores with inoculated seedlings, but no differences were evident. In addition, unfumigated, uninoculated control plants showed no evidence of foliage injury.

Although these results cannot be extrapolated to explain disease development in natural stands of larger trees, they did show that ozone treatments cause a higher percentage of infection and a higher colonization rate of seedlings by *F. annosus*.

Susceptibility of Freshly-Cut Stumps--

Results of infection and surface colonization studies indicates that all inoculated sumps became infected. Results obtained thus far are

TABLE 33. RELATIONSHIP OF CHRONIC OZONE INJURY OF PONDEROSA AND JEFFREY PINE SEEDLINGS TO COLONIZATION OF ROOT CROWN TISSUE BY FOMES ANNOSUS.

Treatment	Ponderosa		Ponderosa		Combined
	Average oxidant injury score	Fungus movement (cm)	Average oxidant injury score	Fungus movement (cm)	Fungus movement (cm)
Filtered air, 1	0.	0.3A*	0.	0.5A	0.4AB
Filtered air, 2	0.	1.3A	0.	1.5A	1.4ABC
Ozone, 4.5+	16.9	0.9A	13.3	1.5A	1.2ABC
Ozone, 9.2	17.5	3.4A	14.9	3.4A	3.4BC

*Values followed by the same capital letters are not significantly different 95 times out of 100.

+Ozone dose as $\mu g/m^3$-hr x 10^5.

summarized in Table 34.

Regression analyses have been completed for "percent surface colonized" vs. pollutant damage score. The significance levels are as follows: ponderosa pine at Barton Flats, $P = 0.025$; ponderosa pine at Camp Paivika, $P = 0.01$; Jeffrey pine at Amphitheatre, $P = 0.25$.

Analyses for downward colonization after six months showed no significance at $P = 0.05$ for either species. The greater rate of downward colonization in Jeffrey pine may be due to seasonal differences. In Jeffrey pine, stumps were inoculated in the spring and dissected the next fall. In ponderosa pine, stumps were inocluated in the fall and dissected the following spring.

Analyses for average stump volume colonized indicated significance for Jeffrey pine at $P = 0.10$, and for ponderosa pine $P = 0.25$. The inoculations on ponderosa pine at Camp Paivika have not yet been dissected to determine downward colonization and volume colonized.

From these data, it appears that air pollution injury increases the susceptibility of pine stumps to colonization by F. annosus. The differences between severely and slightly damaged trees indicate an approximate increase of 100% in surface colonization and about a 50% increase in the rate of colonization over time.

Laboratory Decay Studies--

For the *F. annosus* test, differences existed ($P = 0.05$) showing that wood from trees slightly damaged by air pollution was more decay-susceptible than wood from severely damaged trees. However, conclusions are difficult to reach because of the low percentage (avg. ca 1.5%) weight loss involved.

The test using *Poria monticola* resulted in greater weight loss ($\bar{x} = 60.8\%$) in wood from severely damaged trees than in wood from slightly damaged trees ($\bar{x} = 59.4\%$). Differences were significant ($P = 0.05$). For *Polyporus versicolor*, the same relationship held ($x = 42.0\%$ - severe; 40.7% - slight); however, no significant difference occurred.

These results with *P. monticola* and *P. versicolor* corroborate those reported in the following section ("Woody Litter Decomposition Subsystem") where the meaningfulness of very small differences in decay rate is seriously questioned. The actual quantitative differences are difficult to assess at the present time, and additional work is necessary to properly evaluate the differences.

Cultural Studies--

These studies have just been initiated. Preliminary work indicates that ozone may restrict asexual spore formation in culture; as yet, no quantitative effect on growth rate has been determined.

Miscellaneous Studies--

No results from these studies are yet available.

TABLE 34. STUMP INOCULATION RESULTS

Site	Species	*F. annosus* isolate	Air pollution damage	Surface colonization*/ (%)	Avg. downward+/ colonization (mm)	Avg. volume colonized‡/ (%)
Barton Flats	Ponderosa pine	SV1	very severe-severe	36.9	92.8	15.6
			slight-no injury	17.6	64.5	8.0
Amphitheatre	Jeffrey pine	SV1	very severe-moderate	33.1	307.2	28.1
			slight-no injury	15.8	206.2	8.8
Camp Paivika	Ponderosa pine	JL1	very severe-severe	86.0	ND	-
			slight-very slight	45.9	-	-

*/ One month after inoculation.

+/ Six months after inoculation.

‡/ Six months after inoculation.

TREE SEEDLING ESTABLISHMENT SUBSYSTEM

Introduction

Factors Affecting Seed and Seedling Survival--

The regenerative phase of any forest stand is one of the most important aspects of that stand's biology. Factors affecting seedling establishment are numerous. The health of the cone-producing tree affects the number and quality of cones produced. Weather, disease, insects, avian and mammal predators, and air pollution further determine how many sound seeds are produced and how many survive in the cones. After seeds are shed and before they germinate, they are subject to disease, predation by vertebrates and invertebrates, and such abiotic factors as adverse temperature or moisture conditions. When germination begins, the mortality factors include the same general categories but possibly with different organisms. Similarly, the seedling that survives this far may be killed by any of these mortality factors including air pollution.

Research Objectives

Assays for Incidence of Saprophytic and Pathogenic Fungi in Surface Soils--

Three subobjectives are included. These objectives are:

1) Determine the effect of photochemical air pollutants on soil fungus populations;

2) Determine the abundance of traditional damping-off fungi, specifically *Rhizoctonia* and *Pythium* present in soil across the photochemical air pollution gradient;

3) Determine the abundance of damping-off organisms in the organic horizons compared to those in the mineral soil.

Sampling the Combined Influences of Seed Bed Condition, Fungi, Insects, and Small Vertebrates on Seed and Seedling Survival in the Field--

The three subobjectives are as follows:

1) Determine the individual and joint effects of predators and pathogens on seeds and seedling establishment, and to investigate the influence of pollution on these interactions by establishing the study in stands across an air pollution gradient.

2) Determine the relative importance of pre-emergence damping-off as opposed to post-emergence damping-off.

3) Determine the interaction between litter (quantity and quality) and

the joint effects of the vertebrates, insects, and pathogens on seedling establishment.

Materials and Methods

Sampling for Soil Fungi--

Comparison of populations by dilution isolations--Soil samples were collected from Breezy Point, Camp Osceola, Camp Oongo, Northeast Green Valley, Sky Forest and Snow Valley by using a 3-in diam. tube sampler. Samples were maintained at 2° F until analyzed.

Soils were put through a 2 mm sieve. Then 1 g of soil was added to 100 ml sterile water. This was agitated 60 sec before pipetting 1 ml of the solution to 9 ml sterile water. Agitation and dilution were continued to the desired dilution ratio. Using a sterile pipette, we dispensed 1 ml of each dilution onto labelled petri dishes. Twelve ml of media at 45°-50° C was poured over each plate and the contents swirled to mix them. After 4 days at room temperature, the dilution showing at least 15 colonies/plate was counted and selected cultures were made. Five replications were made for each dilution. The medium used was Potato Dextroxe Agar with 10,000 ppm streptomycin and 1,000 ppm Tergitol.

Isolation of *Rhizoctonia* spp. and *Pythium* spp.--Soil samples were collected from Breezy Point, Camp Osceola, Camp Oongo, Holcomb Valley, Northeast Green Valley, Sky Forest, and Snow Valley by using a 3-in diam. tube sampler. Samples were maintained at 2° F until analyzed.

To sample for *Rhizoctonia* spp. each sample of the organic matter in a known quantity of soil was washed from the soil and distributed sparsely on melted water agar in large petri plates. The plates were incubated at 24° C and checked at 18, 24, 36, and 96 hr for *Rhizoctonia* colonies. Suspect colonies were cultured to confirm identification.

To sample for *Pythium* spp. each 4-g sample of soil was put through a .20 mm sieve, then blended for 60 sec with 100 ml sterile water. Four ml of this suspension were then dropped in .10 ml increments on 3-day-old water agar plates. Plates were checked for growth 18-24 hr later and *Pythium*-like mycelium were cultured as a second check.

Influence of fungi in mineral soil and surface litter on seedling emergence in the greenhouse--Flats of mineral soil and organic material from heavily and mildly smog-affected sites were collected and planted with Jeffrey and ponderosa pine seed. The number of emerging seedlings was noted at frequent intervals and any seedling exhibiting damping-off symptoms was taken to the laboratory for culture.

Sampling for the Influences of Combined Factors on Seed and Seedling Survival in the Field--

Preliminary study of screened and unscreened seed on surface soil with and without litter--A preliminary field study established in May, 1975 at Barton Flats, Camp Oongo, Camp Osceola, and Holcomb Valley followed the status of 3,136 seeds over a one-month period. Four trees on each of four sites were selected with 2 of the 4 relatively healthy and 2 unhealthy with regard to air pollution injury. Four mini-plots were located outside the crown drip line of each tree. The mini-plots for each tree consisted of four treatments:

1) screened with the organic horizon removed;

2) screened with the organic horizon intact;

3) unscreened with the organic horizon removed;

4) unscreened with the organic horizon intact.

Seeds collected from the SBNF during the Fall of 1974 were used to plant the mini-plots.

Comparative survival of screened and unscreened seed on surface soil with and without litter in different seasons--In November, 1975, seeds were collected from healthy Jeffrey pine trees in the SBNF and used in a field study on Camp Osceola, Barton Flats, Holcomb Valley, and Heart Bar. The study was designed with the cooperation of Dr. D. Dahlsten, Dr. M. White, and S. Sweetwood to provide information on the amount and type of seed predation by small vertebrates and arthropods as well as to determine whether differences in seedling establishment due to pathogenic fungi were related to the presence and depth of the organic horizons or to the severity of oxidant levels.

Twenty-eight mini-plots (36 x 36 x 7 cm wood frames with and without ¼ in galvanized screen) on each of the four sites were planted with Jeffrey pine seed. On each site the mini-plots were placed in 4 groups of 6 each and 1 group of 4. The groups of 6 mini-plots included the following treatments:

1) 2 mini-plots screened with the organic horizons removed;

2) 2 mini-plots screened with the organic horizons intact;

3) 1 mini-plot unscreened with the organic horizons removed;

4) 1 mini-plot unscreened with the organic horizons intact.

The group of 4 mini-plots included one each of the 4 treatments listed above.

In Februrary, 1976, the group of 4 mini-plots on each site was destructively sampled to determine the status of seeds after three months in the field. These plots were then replanted. The sites were visited on May 19, June 7, and June 25, 1976. Each time observations were made and dead or dying seedlings were brought back to the laboratory for determination of the cause of death. Seed collected from the February sampling were x-rayed to check for lesions, empty seeds, and any other abnormalities that would indicate an inability to germinate. Abnormal seeds were dissected and "normal" seeds were germinated under controlled conditions to check the X-ray interpretations. Seedlings brought back to the laboratory were surface-sterilized before isolations were made from tissue showing disease symptoms.

Results and Discussion

Assays of Soil Fungi--

Population differences at sites experiencing different chronic oxidant doses--A preliminary analysis of variance of fungal populations among the six plots sampled showed that a significant difference exists among the plots at the .01% level. Further analyses will help determine whether there are population differences primarily due to air pollution, but no trends are obvious at this stage of analysis. The factors affecting soil fungus populations are very complex. Detailed studies are necessary to better understand the role of photochemical air pollution on these organisms. No further data collection is planned.

Rhizoctonia spp. and Pythium spp. at sites experiencing different chronic oxidant doses--Soil assays yielded no Rhizoctonia spp., and Pythium spp. was isolated only once on each of two sites (Breezy Point and Sky Forest) which have "moderate-to-severe" air pollution injury. These sites were characterized by well-developed soils (Shaver series) beneath mixed conifer stands with ponderosa pines. Subsequent studies on seed microflora and litter decomposition studies by J. N. Bruhn have indicated that Pythium and Rhizoctonia may not occur in the humus layer either. We may conclude that neither Rhizoctonia spp. nor Pythium spp. are among the important damping-off pathogens in the forest soils examined. No further work on this study is planned.

Seedling emergence from mineral soil or organic surface litter in the greenhouse--Germination of seeds sown in mineral soil seedbeds was significantly greater (alpha = .01) than germination in seedbeds retaining the natural organic layers. Table 35 summarizes seed germination for this study.

TABLE 35. NUMBER OF SEEDS GERMINATED ON SEEDBEDS WITH AND WITHOUT THE NATURAL ORGANIC LAYERS (400 SEEDS PLANTED IN EACH TREATMENT)

	Vegetation plot				Total	
Nature of seedbed	Barton Flats	Camp Oongo	Holcomb Valley	Camp Osceola	Germ.	Planted
		(No. of seeds)				
With organic material	65	36	81	117	299	1600
Mineral soil only	224	243	232	149	848	1600
Totals	289	279	313	266	1147	3200

The organic horizons of the SBNF soil reduce successful germination of Jeffrey and ponderosa pine seeds. More tests are needed to detail the complex of biotic and abiotic factors causing these results.

Influences of Combined Factors on Seed and Seedling Survival in the Field--

Preliminary study--After one month the mini-plots were examined. Table 36 summarizes seed status at the termination of the study. "Intact" refers to the condition of the seedcoat. An "intact" seedcoat does not necessarily mean the seed is germinable.

TABLE 36. SEED STATUS 30 DAYS AFTER PLANTING.

Site	Planted (No.)	Recovered (No.)	Recovered (%)	Intact (No.)	Intact (%)	Predated (No.)	Predated (%)
Barton Flats	784	313	40.0	178	22.7	135	17.2
Camp Osceola	784	201	25.6	154	19.6	47	5.9
Camp Oongo	784	485	61.9	457	58.3	28	3.6
Holcomb Valley	784	360	45.9	288	36.7	72	9.2
Totals	3136	1359	43.3	1067	34.3	282	9.0

Of 3136 seeds planted, predators are known to have removed 9% and are suspected of having removed a total of 60-66% of the seed. Seed predation, occurring after seed fall, is one of the major causes of seed loss. Of the remaining seed, only 0.3% germinated. Fungi are probably the cause of this low germination rate, but more extensive studies are needed to define their role. Identification of fungi associated with intact seed remaining after one month showed seven fungus species occurring most frequently.

Survival in different seasons--Of 274 seeds checked from the February sampling, 234 (85%) germinated. Analysis for the study is in progress. Periodic observations on the condition of the remaining seedlings will be made throughout the remainder of the project. The current study design should be expanded for future work on this problem.

CONE AND SEED PRODUCTION FOR DOMINANT CONIFER TREE REPRODUCTION

Introdution

To persist, a forest must reproduce itself. This involves the processes of seed production, seed germination, and seedling establishment. In coniferous forest species, seed production is accomplished by the production of an annual cone crop whose abundance varies widely each year (Pearson, 1923; Roeser, 1941; Boe, 1954; Fowells and Schubert, 1956; Daubemire, 1960; Larson and Schubert, 1970). The causes of these annual fluctuations are unknown, but they are thought to be partially the result of weather patterns (Maguire, 1956; Daubenmire, 1960; Lowry, 1966; Puritch, 1972). Furthermore, each species differs in the amount and frequency of the cone crops it produces (Fowells and Schubert, 1956). This difference, coupled with differing requirements for seed germination, seedling establishment, and seedling survival by each species determines the rate of change in the species comprising a stand. Measuring the cone crop patterns of each species thus becomes important in understanding stand succession.

The mixed conifer forests of the SBNF have had a history of photochemical oxidant air pollution exposure, principally to ozone (Miller and Millecan, 1971). Of the species comprising this forest type, ponderosa, Pinus ponderosa Lawson, and Jeffrey pine, P. jeffreyi Greville and Balfour are the two most sensitive species (Miller and Millecan, 1971). In these pines, exposure to ozone reduces the rate of photosynthesis and injures the needle tissue. Both of these effects lead to premature needle abscission (Miller et al., 1969; Evans and Miller, 1972: Miller, unpublished data).

Ponderosa and Jeffrey pines injured by ozone have crowns which appears similar to those used to define the low vigor classes employed in rating pines subjected to higher risks of bark beetle attack (Keen, 1936) and in evaluating the growth potential of pines following selective logging (Hornibrook, 1939; Thompson, 1940). Larson and Schubert (1970), using the vigor classes employed to evaluate growth potential (Thompson, 1940), found that trees of low vigor (sparse complement of needles within the crown) produced substantially fewer cones. Therefore, the sparse crown foliage resulting from abscission of ozone-injured needles, coupled with reduced photosynthesis in those needles that remain, suggest that oxidant-sensitive trees may produce fewer and smaller cones, less frequent cone crops, fewer seeds per cone, and lower seed viability. This subsystem is indicated in Figure 55.

Research Objectives

There are two primary objectives to this study:

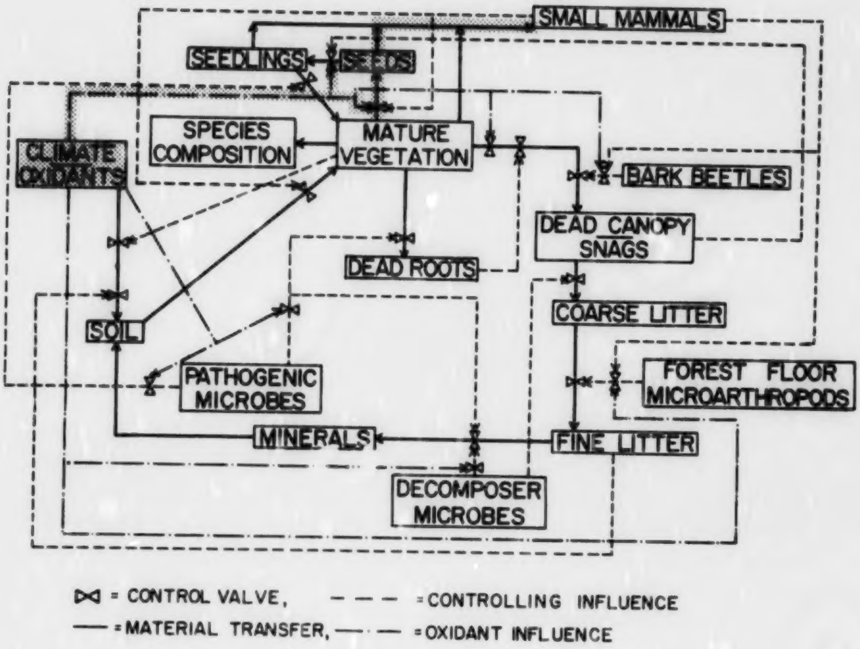

SMALL MAMMALS
SEEDLINGS
SEEDS
SPECIES COMPOSITION
MATURE VEGETATION
CLIMATE OXIDANTS
BARK BEETLES
DEAD CANOPY SNAGS
DEAD ROOTS
COARSE LITTER
SOIL
PATHOGENIC MICROBES
FOREST FLOOR MICROARTHROPODS
MINERALS
FINE LITTER
DECOMPOSER MICROBES
⋈ = CONTROL VALVE,
– – – = CONTROLLING INFLUENCE
—— = MATERIAL TRANSFER,
—·— = OXIDANT INFLUENCE

Figure 55. Conifer seed production subsystem.

1) To test the hypothesis that cone crop abundance and frequency in ponderosa and Jeffrey pines are affected by ozone injury.

2) To describe the probability for a given tree of producing a cone crop in a given year. A number of factors are known to affect cone production (Fowells and Schubert, 1956; Larson and Schubert, 1970); hence, this description will require the identification of certain tree characteristics, such as species, age class, vigor class, ozone-injury class, and other variables such as temperature patterns or soil moisture depletion rates which are likely to affect that probability. The description will be used in a submodel of cone production and can be integrated with a stand succession model.

Materials and Methods

Estimating Cone Crops--

Cones within the crowns of all conifers on the 18 established plots were counted visually with the aid of binoculars. Although these counts underestimate the actual number of cones within the crown, they reveal the pattern of annual cone production, identify those trees which produce cones and provide an order of magnitude estimate of cone abundance (Roeser, 1941; Fowells and Schubert, 1956, Daubemire, 1960). Their inaccuracy, however, suggests the need for a second estimate of cone abundance. This was

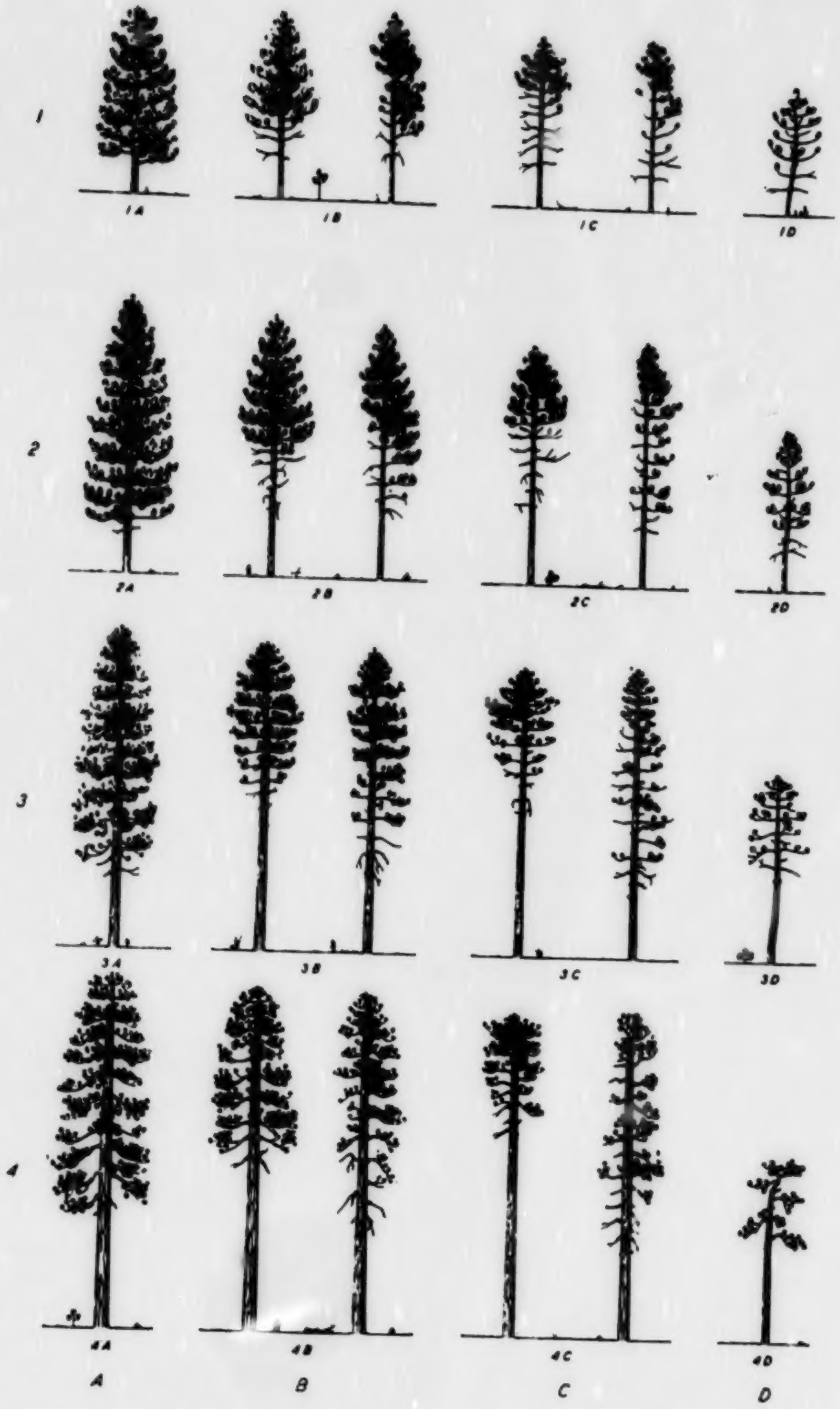

1
1A
1B
1C
1D
2
2A
2B
2C
2D
3
3A
3B
3C
3D
4
4A
4B
4C
4D
A
B
C
D

Figure 56. Examples of Keen's tree age and growth vigor classes for east side Sierra Nevada and southern California ponderosa pine (Keen, 1936).

obtained by counting the cones after they have fallen to the ground. They were recorded by assigning them to the trees from which they fell. In cases where the crowns of two or more trees were interlaced, cones were partitioned among the trees in proportion to the number of cones counted in each of their crowns. (This latter point suggests a fourth reason for the need of visual cone counts.) The cones were collected periodically in the spring and summer of the year following production of a given cone crop. Very few cones from the previous year's crop remain in the tree crowns by the time the next crop is produced (Larson and Schubert, 1970). Counts of cones on the ground are applicable only to the pines (sugar pine, ponderosa pine, Jeffrey pine), and possibly to incense cedar, Libocedrus decurrens Torrey. Cones can be counted on the ground and their year of production determined (Pearson, 1923; Larson and Schubert, 1970). The cones of white fir, Abies concolor, disintegrate in the process of seed dispersal.

Cones collected in the 18 plots were used to estimate the incidence of cone insects, the incidence of predation on cones by squirrels, and the frequency distribution of seeds produced per cone. The incidence of cone insects was obtained by placing aborted or unopened cones in individual containers and rearing out the insects they contain. The specimens which emerged were identified and their damage characteristics determined. An estimate of the number of seeds per cone was made by counting the number of seed niches present in the bracts in fifty cones. These cones were also cut along the axis and the presence or absence of insect damage noted. Incidence of cone predation by squirrels is evidenced as the number of immature cones on the ground upon which feeding has occurred. The effect of squirrel predation is being studied in conjunction with investigations on small mammals.

Additional information was taken from trees on all of the plots. Trees were classified on the basis of their age, height, crown class (Table 37), vigor class (Fig. 56), length of live crown and location within a stand (on the margin or in the interior). All these factors are known to be associated with cone abundance and cone crop frequency (Fowells and Schubert, 1956; Larson and Schubert, 1970). These additional data have been taken on 8 of the 18 plots. Additional plot and tree data was obtained from the other subprojects and this subproject will supply data to them in return. Multivariate analysis (multiple regression, stepwise regression or variance-covariance analysis, for example) will be used to identify the relationship of cone crop to the independent variables discussed above.

Results and Discussion

Counts of Cone-Bearing Trees and Cone Production--

Most of the data presented below is preliminary. The 1974 cone crop was the first one counted visually in the 18 plots. Only a portion of the plots were counted in 1973 because plot establishment was not completed prior to the loss of many of the cones from the trees. Lack of these counts prevented assigning the fallen cones to the trees from which they came in those tree groups whose crowns interlaced. Furthermore, cone data for 1973 do not include losses due to insects or squirrels. The 1973 cone data,

TABLE 37. DESCRIPTION OF CROWN CLASS CHARACTERISTICS

Crown Class	Description
Dominant	Trees whose crowns extend above the general crown level.
Codominant	Trees whose crowns form the general crown level.
Intermediate	Trees whose crowns extend into the general crown level.
Intermediate open	Trees substantially smaller in diameter and height than those that generally characterize the stand but are isolated, free to grow on all sides.
Intermediate suppressed	Trees which are of similar diameter as those which generally characterize the stand but whose crown lies entirely below the general crown level.
Suppressed	Trees which are smaller in diameter than those which generally characterize the stand and whose crown lies entirely below the general crown level.

however, provide a reliable estimate of the number of trees which produce a cone crop. Ground counts of the cone crop began in spring 1975 and these represent the count of the 1974 cone crop. Cones lost to insects, squirrels, and unknown sources were incorporated into these counts. It should be noted that most all of the additional tree and plot data are still being acquired; thus, the effect of oxidants on cone production in ponderosa and Jeffrey pine cannot be addressed, since the data are still in various stages of analysis.

Visual counts of annual cone crops (1973-76) born by ponderosa pine are summarized in Table 38a,b; those for Jeffrey pine are summarized in Table 39a,b. Crown classifications used in Tables 38 and 39 are defined in Table 37. The visual counts for those cone crops are summarized by plot in Appendix K.

A greater percentage of ponderosa and Jeffrey pine in the dominant crown class produce cones; codominant ones are the next most frequent bearers (Tables 38 and 39). Dominant ponderosa pines represent 33% of the individuals of this species present on the plots, but they account for 63% (60-66% range) of the cone-bearing individuals and produce 68% (61-73% range) of the cones born by this species. Similarly, dominant Jeffrey pines comprise only 28% of the individuals of this species on the plots but account for

TABLE 38a. INFLUENCE OF CROWN CLASS ON THE NUMBER OF TREES WHICH PRODUCED CONES AND THE NUMBER OF CONES PRODUCED BY PONDEROSA PINE IN 1973 and 1974 IN 18 PLOTS.

		Crown Class					
Year	Numbers	Dominant	Codominant	Intermediate	Intermediate open	Intermediate suppressed	Suppressed
1973	# trees	205	196	125	75	46	56
	# trees with cones	44	18	0	2	0	0
	Total cones	3039	462	0	9	0	0
	% trees with cones	21.46	9.18	0	2.67	0	0
	Average # cones/cone	69.07	25.67	--	4.50	--	--
1974	# trees	241	215	134	75	43	54
	# trees with cones	150	89	8	3	0	0
	Total cones	11384	3882	157	75	0	0
	% trees with cones	62.24	41.40	5.97	4.00	0	0
	Average # cones/cone	75.89	43.62	19.63	25.00	--	--

TABLE 38b. INFLUENCE OF CROWN CLASS ON THE NUMBER OF TREES WHICH PRODUCED CONES AND THE NUMBER OF CONES PRODUCED BY PONDEROSA PINE IN 1975 AND 1976 IN 18 PLOTS.

		Crown Class					
Year	Number	Dominant	Codominant	Intermediate	Intermediate open	Intermediate suppressed	Suppressed
	# trees	239	213	129	72	21	53
	# trees with cones	38	19	0	1	0	0
1975	Total cones	210	131	0	1	0	0
	% trees with cones	15.90	8.92	0	1.39	0	0
	Average # cones/cone trees	5.53	6.89	--	1.00	--	--
	# trees	238	212	124	71	19	51
	# trees with cones	119	56	5	7	0	1
1976	Total cones	4555	1939	11	36	0	4
	% trees with cones	50.00	26.42	4.03	9.89	0	1.96
	Average # cones/cone tree	38.28	34.63	2.20	5.14	--	4.00

TABLE 39a. INFLUENCE OF CROWN CLASS ON THE NUMBER OF TREES WHICH PRODUCED CONES AND THE NUMBER OF CONES PRODUCED BY JEFFREY PINE IN 1973 AND 1974 IN 18 PLOTS.

		Crown Class					
Year	Number	Dominant	Codominant	Intermediate	Intermediate open	Intermediate suppressed	Suppressed
1973	# trees	189	134	80	111	29	54
	# trees with cones	89	20	2	2	1	0
	Total cones	756	167	7	3	3	0
	% trees with cones	47.09	14.93	2.50	1.80	3.45	0
	Average # cones/cone tree	8.49	8.35	3.50	1.50	3.00	--
1974	# trees	232	191	150	150	25	93
	# trees with cones	121	56	17	3	3	0
	Total cones	5571	411	206	6	12	0
	% trees with cones	52.16	29.32	11.33	2.00	8.00	0
	Average # cones/cone tree	46.04	7.34	12.12	2.00	4.00	--

TABLE 39b. INFLUENCE OF CROWN CLASS ON THE NUMBER OF TREES WHICH PRODUCED CONES AND THE NUMBER OF CONES PRODUCED BY JEFFREY PINE IN 1975 AND 1976 IN 18 PLOTS.

		Crown Class					
Year	Numbers	Dominant	Codominant	Intermediate	Intermediate open	Intermediate suppressed	Suppressed
1975	# trees	231	191	148	150	25	92
	# trees with cones	118	53	9	6	0	0
	Total cones	3116	551	28	16	0	0
	% trees with cones	51.08	27.75	6.08	4.00	0	0
	Average # cones/cone	26.41	10.40	3.11	2.67	--	--
1976	# tree	231	188	145	150	25	91
	# trees with cones	190	101	41	34	5	5
	Total cones	10327	1722	667	221	11	34
	% trees with cones	82.25	53.72	28.28	22.67	20.00	5.49
	Average # cones/cone trees	54.35	17.05	16.27	6.50	2.20	6.80

58% (51-63% range) of the cone-bearing individuals and produce 85% (80-90% range) of the cones born by this species. Clearly the dominant crown classes are the greatest contributors to the cone crop. These findings agree with those of Pearson (1923), Fowells and Schubert (1956), and Larson and Schubert (1970).

Tentatively, it appears that the type of tree which contributes the most cones to a given annual crop has a large diameter (larger than 50 cm), is isolated from its neighbors or on the margin of a stand, has a good complement of needles, and belongs to the dominant crown class.

Seed Production--

Twenty-five ground cones from each plot were used to estimate the 1975 seed crop. A sample size of 25 cones was chosen because the standard deviation stabilized at this sample size and it generally provided a standard error of at least 10% of the mean. The average number of seed impressions per cone with the associated standard error for those plots which produced cones (as measured by visual counts) in 1975 is summarized in Table 40. Also Table 40 provides estimates for the number of seeds produced by each plot.

There are two major sources of error associated with these estimates. First, estimates of the number of seeds per cone include all seeds which swelled enough to leave an impression in the bract. These estimates include unfilled seeds; thus, they overestimate the number of viable seeds per plot. Second, the number of cones per plot estimated by visual cone counts underestimates the size of the cone crop. The smaller cone crops are more subject to error since they are generally borne as single cones on a branch. This tendency increases their likelihood of being obscured by foliage. Larger cone crops are generally borne as clusters on a branch and are thus more easily seen. Furthermore, the number of cones per plot has not been corrected for losses due to insects, squirrels, and unknown causes.

Even with these errors, however, it is clear from Table 40 that five of the seven plots dominated by Jeffrey pine produced a substantial number of seeds in 1975. The Snow Valley (SV) and Green Valley Creek (GVC) plots, both of which produced a light cone crop in 1975, are both lower in elevation and more exposed to oxidant air pollution. However, inspection of the cone crop data in 1974 indicates that the trend in the Jeffrey pine plots was the reverse of that observed in 1975; GVC and SV had a heavier 1974 cone crop while the remaining 5 plots had lighter ones that year (Appendix K). The increased cone crops on the 5 Jeffrey pine plots in 1975 perhaps indicate a one year time lag in response.

Agents of Mortality: Insects--

Table 41 lists those insect species which have been reared from ponderosa and Jeffrey pine cones and identified by experts at the U.S. National Museum. This list is incomplete because the cone moths and chalcid hymenoptera (parasitoids) have not yet been returned from the museum. Of those species listed in Table 41, two are generally thought to damage cones: Conopthorus ponderosae Hopkins and the three species

TABLE 40. ESTIMATES OF THE NUMBER OF EXPANDED SEEDS PER CONE AND TOTAL SEED CROP PER PLOT FOR THE 1975 CONE CROP.

Plot	$\bar{x}$ Seeds/ cone	Estimated seed crop	Sample size for seed/cone estimate
	Ponderosa Pine		
BP	70.77 ± 6.11	1,332	22
CAO	105.76 ± 3.61	740	25
COO	85.24 ± 6.40	341	25
CP	73.61 ± 7.22	1,472	23
DW	78.60 ± 9.38	2,206	10
SF	110.68 ± 4.19	6,751	25
TUN 2	101.52 ± 2.25	812	25
UCC	111.92 ± 6.03	895	25
	Jeffrey Pine		
BL	111.76 ± 5.55	18,216	25
GVC	48.80 ± 2.38	732	25
HB	115.92 ± 8.51	106,762	25
HV	124.20 ± 5.51	56,883	25
NEGV	109.48 ± 4.65	30,544	25
SC	42.76 ± 3.33	79,747	50
SV	143.56 ± 7.70	143	25
	Mixed		
SCR	101.52 ± 7.85	1,624	25

TABLE 41. INDENTIFIED INSECT SPECIES REARED FROM JEFFREY AND PONDEROSA PINE CONES.

Species observed	Role
Coleoptera	
Scolytidae	
Conophthorus ponderosa Hopkins	attacks cones
Ptinidae	
Ptinus aquatus Fall	attacks cones or is a scavenger
Cleridae	
Cynatodera ovipennis LeC	predator
Lathridiidae	
Microgramme filum Aube	scavenger
Corticaria clentigera L.	scavenger
Dermestidae	
Megatomz (prob.) *variegata* Horn	scavenger
Anobiidae	
Ernobius melanoventris (or near) Ruckes	attacks cones
Ernobius (prob.) *montanus* Fall	attacks cones
Ernobius socialist (or near) Fall	attacks cones
Neuroptera	
Hemerobiidae	
Sympherobius californicus Bks	predator
Raphiidiae	
Rhaphidia flexa Carp	predator
Dipter	
Drosophilidae	
Drosophila (Dorsilopha) *busckii* Coquillett	fungus feeder
Chloropidae	
Hapleginella cornicola Green	?
Chironomidae	
Orthocladiinae	scavenger
Hymenoptera	
Braconidae	
Eubazus sp	parasitoid
Apanteles sp	parasitoid
Chelonus (*Microchelonus*) sp.	parasitoid
Platygasteridae	
Platygaster sp	parasitoid
Bethylidae	
Cephalonomia hyalinipennis	parasitoid

of Ernobius. Cone losses to both the 1974 and 1975 cone crops were not substantial.

Agents of Mortality: Squirrel--

Squirrels accounted for the greatest loss of cones in both the 1974 and 1975 cone crops. This loss occurs in the second summer of cone maturation, but the impact has yet to be assessed quantitatively. Further discussion of squirrel predation can be found in the section: "Small Mammal Population Dynamics Subsystem".

LITTER PRODUCTION SUBSYSTEM

Introduction

It is clear that air pollutants affect the production of litter from the fact that the number and size of needles on the trees decline with increasing air pollutant damage. In order to document the changes, we measured litter production, mass and thickness of the forest floor, and size and composition of needles in the litter fall under trees in various stages of decline due to air pollutants. It was also assumed that changes in the forest floor caused by change in the kind and amount of litterfall affect the upper part of the soil and the forest floor as habitats for flora and fauna being studied in other subprojects. These changes may be important to seedling survival and, thus, to the succession of forest vegetation.

Research Objectives

This project had five research goals along the oxidant injury gradient:

1) To measure needle litter on the forest floor.

2) To measure the rate of needle litter accumulation.

3) To measure the nutrient content of needle litter from trees with a range of oxidant injury.

4) To measure the effect of tree crown injury on interception of precipitation and nutrient composition of crown drip.

5) To measure surface soil nutrients under ponderosa and Jeffrey pines with range of oxidant injury.

Materials and Methods

Measuring Needle Litter on the Forest Floor--

In order to document the status of accumulated organic matter (pine needles, twigs, etc.) on the forest floor of the various study plots in relation to the impact of air pollutants on the pine forest, the thickness of the litter layer was measured at 2 m intervals along a line transect for the length of the plots. In addition, core samples of the litter layer were collected at 135 representative sites, in order to establish the relationship between mass and thickness (T) of the layer in cm.

Measuring the Rate of Needle Litter Accumulation--

As a result of injury to vegetation due to oxidant air pollutant and related pathogenic and bark beetle interactions, dead organic matter accumulates on the forest floor in the form of needle litter and coarse woody fragments.

Litter fall was collected on 0.209 m^2 screens (18 in square) on 6 trees in the fall of 1973 and under 39 trees in the fall of 1974. Oxidant injury ratings ranged from 3 (severe injury) to 33 (slight injury) in 1973, and from 9 (severe injury) to 44 (no injury) in 1974. Needles were separated from other litter, and the mass per fascicle of needles was determined to obtain a measure of the size of the needles in the litter fall. Total needle and other litter weight were also measured. Needle-fall from selected trees has been analyzed for its content of nitrogen, phosphorus, potassium, calcium, and magnesium.

The organic forest floor was sampled with a core-cutter at 110 sites under 52 pine trees variously affected by oxidant air pollutants, and the mass per unit area was related to thickness. Using these data and transect measurements of thickness on 12 major plots, we estimated the total amount of litter on the forest floor. The forest floor was also measured in radial lines from the trunks of somewhat isolated individual pine trees and the pattern of needle litter accumulation on the forest floor was determined.

Measuring the Nutrient Content of Needle Litter from Trees with a Range of Oxidant Injury--

The methods of analysis have been described above in "General Description of Ecosystem Properties: Soils".

Measuring the Effect of Tree Crown Injury on Interception of Precipitation and Nutrient Composition of Crown Drip--

The amount, distribution, and composition of crown drip under pine trees variously affected by air pollution injury was studied to examine the effect of air pollution on the forest floor (litter layers) and the surface soil. Nine ponderosa pine trees were sampled at the Camp Oongo plot, with oxidant injury ratings from 10 (severe) to 34 (slight). Random radial lines of collector cans were set on stakes at 0.5 m intervals out from the tree trunk to 1.0 m outside the drip line. Precipitation and crown drip were collected and the volume measured at 173 sites, an average of 19 samples around each tree immediately following the first period of precipitation in the fall which occurred in the last week of October, 1974. Of these samples, 66 (7 or 8 per tree) were selected at random and analyzed for calcium, magnesium, potassium, sodium, and phosphorus. Crown drip was collected at 127 sites under 24 trees on the Camp Oongo plot following a single fall rain including a little light snow on October 31, 1975.

Measuring Surface Soil Nutrients Under Ponderosa and Jeffrey Pines with a Range of Oxidant Injury--

Soil samples collected from the surface of the mineral soil to a depth of 7.5 cm under 40 pine trees (3 or 4 per tree) were analyzed for the percentage of organic carbon and nitrogen, and exchangeable sodium, potassium, calcium and magnesium. The methods of analysis were described above in "General Description of Ecosystem Properties: Soils".

Results and Discussion

Variation of Needle Litter Thickness on the Forest Floor--

The relationship of litter thickness (T) to litter mass was calculated by regression analysis: this showed that

$$\text{Mass (kg/m}^2\text{)} = 1.249\ T + 1.329$$

The correlation coefficient was 0.902, and the regression line was calculated to be not significantly different from one passing through the origin (T=0, Mass=0), which gave us the following equation:

$$\text{Mass} = 1.4\ T$$

Using this equation, we calculated the average amount of litter on the forest floor from the average thickness measured. However, we found that the litter layer on the forest floor of some plots had been stripped away by recreational and logging activities. In order to obtain meaningful averages, these areas were treated separately. Results are shown in Table 42. The thickest forest floor was found on undisturbed areas of Dogwood, Sky Forest, U.C. Conference Center, Camp Paivika, Breezy Point, and Camp Angelus. Relatively thin layers were found on undisturbed plots at Snow Valley, N.E. Green Valley, and Holcomb Valley, but none of these was as thin as the disturbed areas of Dogwood, Green Valley Creek, Holcomb Valley, and Camp Osceola. The very marked reduction in thickness of the forest floor by recreation activities (mainly motorcycles) any by logging (even scattered sanitation logging removing oxidant-injured or insect-infested trees) may have important consequences on seed germination, seedling survival, soil temperature and moisture, animal habitats, and fire behavior.

On the other hand, the accumulated needle litter, fallen (unharvested) trees killed by the oxidant-injury/bark beetle complex, and the accumulated slash from repeated sanitation salvage logging have resulted in serious fuel overloads at places like Sky Forest. The implication is that wildfires could cause death of even large trees because of sustained high temperatures.

Effect of Oxidant Injury to Tree Crowns on Rate of Litter Accumulation--

One of the most obvious effects of air pollutants on the ponderosa and Jeffrey pine trees is the decrease in size and number of needles on the tree. It is clear that as injury to the tree increases, older needles fall from the tree and increase litter-fall until most of the older needles are on the ground, and the production of new needles is low. The mass of needles collected on screens placed under pine trees from September 10 to December 11, 1974--the period of normal needle-fall with minimal effect of snow breakage of the tree--is shown for the Lake Arrowhead region (Camp Paivika to Camp Oongo) in relation to the oxidant injury score for individual trees in Figure 57.

TABLE 42. MASS AND THICKNESS OF THE FOREST FLOOR ON MAJOR STUDY PLOTS.

Plot	Sample Size Number	Mean Thickness, T (cm)	Standard Deviation of T	Mass* (Kg/m^2)	Standard Deviation of mass
DWA	20	12.5	±1.23	17.61	±1.73
(disturbed)	(66)	(2.8)	(±0.42)	(3.92)	(±0.59)
SF	102	10.7	±0.43	15.11	±0.61
UCC	32	11.1	±1.03	15.73	±1.45
CP	76	10.3	±0.48	14.52	±0.68
BP	49	9.4	±0.50	13.23	±0.71
TUN 2	81	8.4	±0.54	11.8	±0.76
COO	84	7.5	±0.43	10.56	±0.61
GVC	20	8.4	±0.54	11.81	±0.76
(disturbed)	(60)	(3.3)	(±0.34)	(4.71)	(±0.48)
NEGV	127	5.3	±0.3	7.47	±0.47
SV	138	4.2	±0.39	5.91	±0.55
HV	77	5.2	±0.42	7.32	±0.59
(disturbed)	(52)	(1.3)	(±0.19)	(1.84)	(±0.27)
BL	110	6.6	±0.39	9.35	±0.55
CA	74	9.8	±0.55	13.75	±0.78
CAO	62	6.6	±0.40	9.27	±0.56
(disturbed)	(24)	(2.6)	(±0.29)	(3.65)	(±0.41)
Range (undisturbed)		4.2/12.5		5.91/17.61	

---

*Calculated mass = 1.41 T

The oxidant injury scores determined by another subproject for these trees ranged from 9 (severe impact) to 34 (very slight impact). It can be seen readily that needle-fall was low in the relatively healthy trees (oxidant injury score > 25); but as the injury becomes increasingly severe, needle-fall increases to a maximum where the average injury score is about 15 and drops again to low values in the severely injured range (oxidant injury score 9 and 10). Trees with "severe" injury retain only the current and previous year's needles, which are relatively short in length. The variation in litter caught on the screens was quite large under those trees with oxidant injury scores ranging from 14 to 19, but otherwise the data appear to represent significant changes with time.

The oxidant air pollutants also affect the size of needles in the needle-drop collected. The length--or, more properly, the average mass per cluster of 3 needles (fascicle)--is shown in Figure 58 in relation to the oxidant injury score. The decreased mass as the impact grows more severe is clearly shown and is highly significant. Each point on Figure 58 represents a single tree.

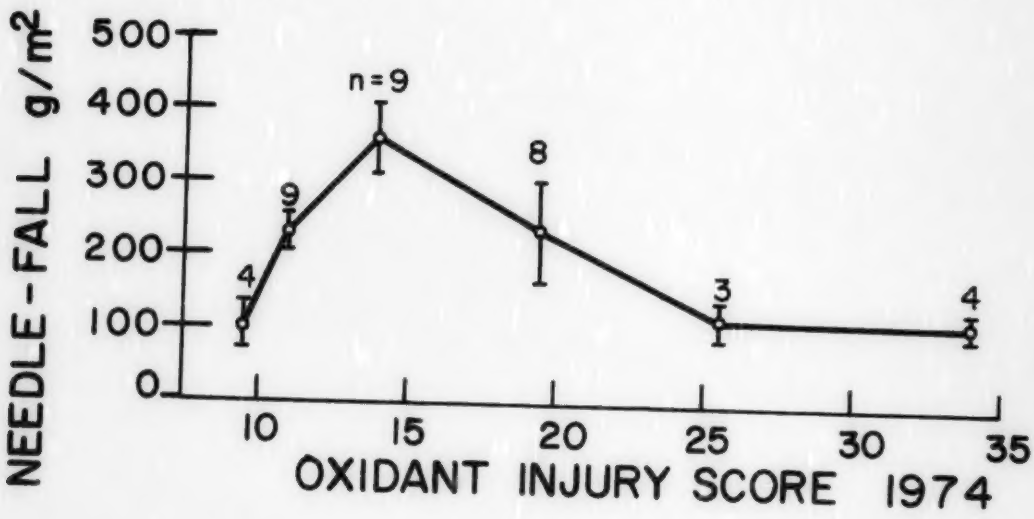


Figure 57. Mass of ponderosa pine needle litter-fall compared to oxidant injury score, 1974; for Camp Paivika plot to Camp O-Ongo plot.

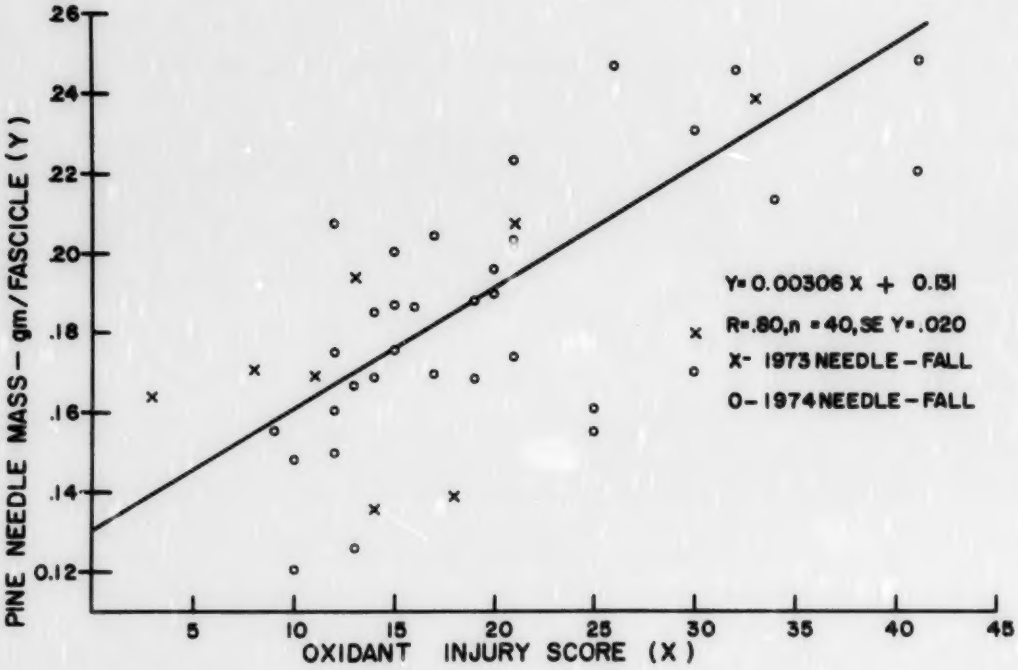


Figure 58. Ponderosa and Jeffrey pine needle-fall compared to oxidant injury score, Sept. - Dec., 1973 and 1974.

Nutrient Content of Needle Litter from Trees with a Range of Oxidant Injury--

Preliminary results from analysis of needles from 5 selected trees in 1973 are shown in Table 43.

Evidence for an effect of air pollutants on nutrient content of needlefall is inconclusive, but it appears that severely affected trees with oxidant injury scores of 3 to 11 are higher in nitrogen (N) content than those less affected (oxidant injury scores 21, 33).

The content of N, P, K, Ca, and Mg has been determined on samples collected on screens under pine trees in spring and late fall from 12/73 to 5/75. Examination of the data reveals no clear relationships between nutrient content of the needles and the impact of air pollutants. However, clear evidence of loss of nutrients due to leaching by precipitation, particularly for potassium and magnesium, is shown by the data in Table 44.

Data from two trees (COO 852 and 856) showed a marked decline in N, P, K, and Mg content between fresh-fallen needles collected on September 15 before any fall rain and those affected by light autumn precipitation to those collected in May after heavy winter precipitation and snow melt. The data in Table 44 are representative of a large volume of data for samples collected from 40 trees (2 to 4 samples per tree) which is to be analyzed by computer.

TABLE 43. CONTENT OF NUTRIENT ELEMENTS IN NEEDLE FALL COLLECTED IN AUTUMN, 1973.

			Nutrient					
Plot	Tree no.	Oxidant injury score	P	K	Ca	Mg	N	C
					(mg/100g)			
COO	A1-449	33	44	199	357	123	426	543
UCC	A1-448	21	50	246	417	141	403	532
COO	GO-863	11	66	336	355	103	444	521
SF	GO-1244	8	56	285	363	155	670	542
UCC	A1-405	3	48	242	173	79	532	526

TABLE 44. NUTRIENT CONTENT AND LOSS IN NUTRIENTS DUE TO LEACHING OF NEEDLE-FALL FROM PINE TREES.

			Nutrient				
Plot	No. of trees	Date Fresh	N	P	K	Ca	Mg
					(mg/100g)		
COO	5	9-15-74	786	101	510	359	123
COO	9	11-74	501	64	289		
COO	9	5-75	601	52	81	445	86
Percent loss		9-74/5-75	245	49	84	---	30

The losses indicated are all significant ($P < .001$)

This loss in nutrients due to leaching does not reflect the total loss since it is reported on a weight basis. At the same time, the total weight of needles is declining. The average mass per needle fascicle declined from fall, 1974 to May, 1975 from 0.179 g to 0.156 g, for a total weight loss of 18 percent. Applying this correction to the data in Table 44, losses of the original weight were 37, 57, 87, and 43% and an apparent increase of only 2.6% in Ca, indicating only a small weight loss between September and December, 1974.

The needle-fall was collected under the same trees which other subsections have been studying with respect to micro-arthropods, microorganisms, and seedling germination. These changes in nutrient status can not be integrated into those studies.

Effect of Oxidant Injury to Tree Crowns on Interception of Precipitation and Crown Drip Nutrient Composition--

Interception in 1974--An interesting observation is that the crown drip under trees 1.0 to 3.0 m from the trunk exceeded the precipitation measured 1.0 to 2.0 m outside the crown line of the tree. Precipitation averaged 79.2 mm, while the average crown drip was 90.2 mm. The difference is highly significant since statistical analysis indicates this difference to be real in 99 out of 100 cases. Generally, interception of precipitation by vegetation is thought to decrease the amount of water reaching the ground surface. However, in these mountain regions, precipitation is generally accompanied by considerable wind. Apparently, the fact that rain falls at an angle, rather than vertically, accounts for the fact that less than the total precipitation reaches the ground between trees. Presumably, the true precipitation, if it were measured above the forest, would be between the two values of 90.2 and 79.2 mm.

Crown drip nutrients in 1974--Collected crown drip and precipitation were analyzed for calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and phosphorus (P). The most striking feature of the results is the increase in total cations (Ca, Mg, K, and Na) with decreasing distance from the trunk, although some high values were found (> 20.0 mg/l) up to 2.0 m from the trunk. It appears that precipitation drips from ponderosa pine needles to limbs near the center of the tree crown before falling to the ground. The high values appear to be from drip from the limbs, rather than directly from needles. The general relationship is shown clearly in Figure 59.

This variation apparently obscures any effect that air pollutant injury may have on the composition of crown drip. The content of total cations in crown drip is shown in relation to oxidant injury score in Figure 60. The two lowest values do show up on the trees with the most severe impact (injury score 10 and 11), but the others do not show a corresponding relationship.

Interception in 1975--Precipitation measured with collectors (99 mm in diameter) was 19.4 mm. The average amount of crown-drip caught in similar collectors under 24 trees plotted in relationship to air pollutant injury rating (I) is shown in Figure 61. There was no evident relationship shown between (I) and the amount of crown-drip; however, net interception of precipitation by the tree crown is apparent for only 8 trees, whereas the crown-drip exceeded the precipitation under 16 trees. This increase was attributed to the effect of wind in introducing a horizontal component to the angle of falling raindrops, thus increasing the effective precipitation under the trees and reducing it on their down-wind side. Since the base line precipitation was measured on an open hilltop, the measurement is probably accurate.

Crown drip nutrients in 1975--The effect of air pollutant injury on the composition of crown-drip is much more evident than on the amount

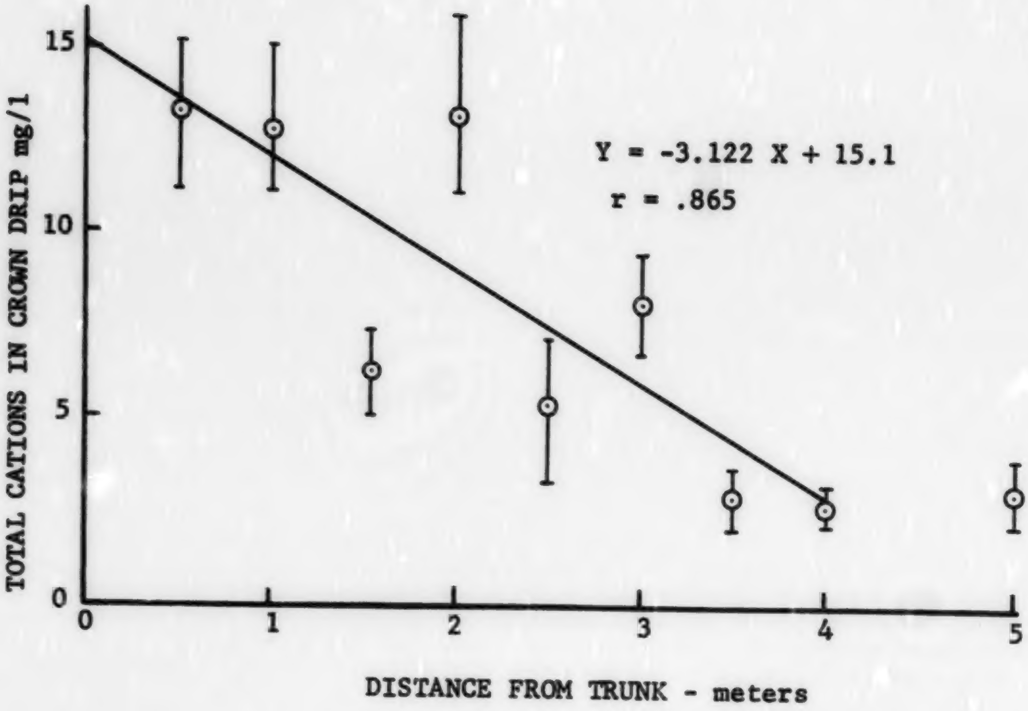


Figure 59. Crown drip cation concentration in relation to distance from ponderosa pine tree trunk.

(Fig. 62). The average amount of total cations (Ca, Mg, K, and Na) increased with the injury score (I) from .014 g/M^2 in the precipitation to about 0.26 g/M^2 for the slightly affected or unaffected trees (I = 30 to 40). Severely affected trees (I = 6 to 12) yielded about 0.1 g/M^2. Two trees yielded very high amounts of cations (> 0.3 g/M^2), but these results do not fit the general relationship, and the reason has not been explained.

Although one might expect an increase of nutrients leached by crown-drip from the tree with increased air pollutant injury, the trees are also being defoliated by the injury; thus, there is less contact between precipitation and the foliage on severely affected trees, and fewer cations are being leached. These results need to be related to the crown density measurements made by the vegetation subproject and to nutrient status of intact needles.

Variation of Soil Surface Nutrient Content Under Ponderosa and Jeffrey Pines with a Range of Oxidant Injury--

Preliminary inspection of results indicated no evident relationships from 18 trees in the higher rainfall areas (plots: COO, SFRS, DL, TUN2, BP, NWCP). However, significant correlations were observed between air pollutant injury ratings (I), and exchangeable Ca, K, and Mg for trees in

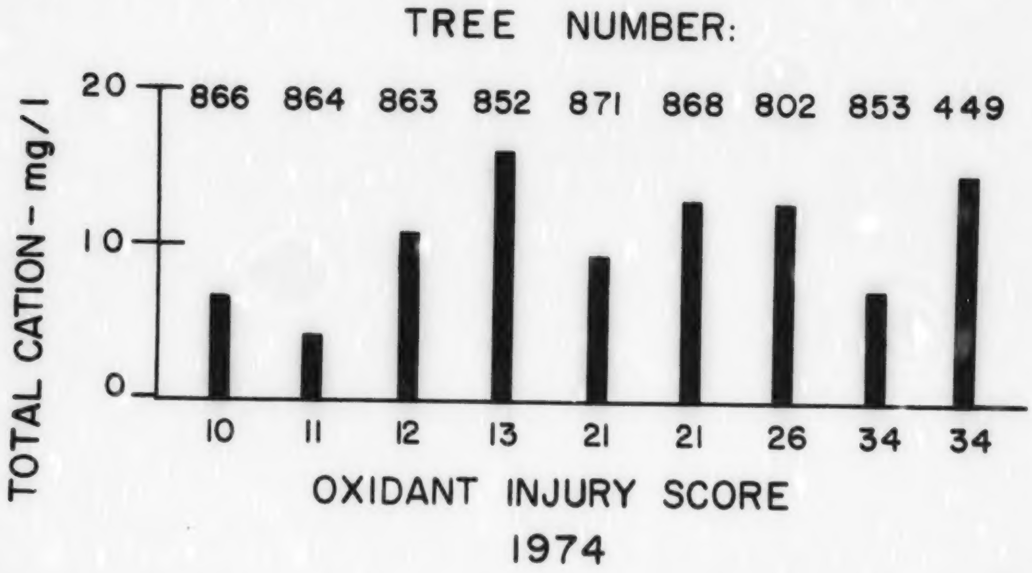


Figure 60. Crown drip cation concentration in relation to oxidant injury score of ponderosa pine.

the lower rainfall areas of Santa Ana Canyon (plots: CA, SCR, BF, CAO) and plots on the north side of the San Bernardino Mountains (UCC, GVC, NEGV, and HV).

The relationships observed were significant only when soils with unusually high organic carbon content (> 3.0%) were excluded. The trend indicated in Figure 63 indicates that soil K increased as the injury score decreased (indicating increased injury). A similar trend for Ca was indicated in Figure 64 and the correlation is even more significant. The trend was about the same also for the Mg as shown in Figure 65.

Since very high soil carbon produced unusually high values for exchangeable Ca, K, and Mg, the relationship of organic carbon and air pollutant injury score was also investigated for the same trees, but there was found to be no direct correlation. The correlation coefficient was -.114, which is not significant.

Soil N is generally highly correlated with soil organic C and so, as expected, the correlation of N with air pollutant injury rating was also found to be non-significant (r = -.184). However, both Ca and K are significantly correlated with organic C in the soil (r = .645 and .459); thus, it is likely that some of the trend with respect to air pollutant impact was a reflection of soil carbon. However, this may not be entirely true since soil C is not correlated with air pollutant impact. To unravel these relationships, it will require multivariate analysis, which will be carried out in the coming year.

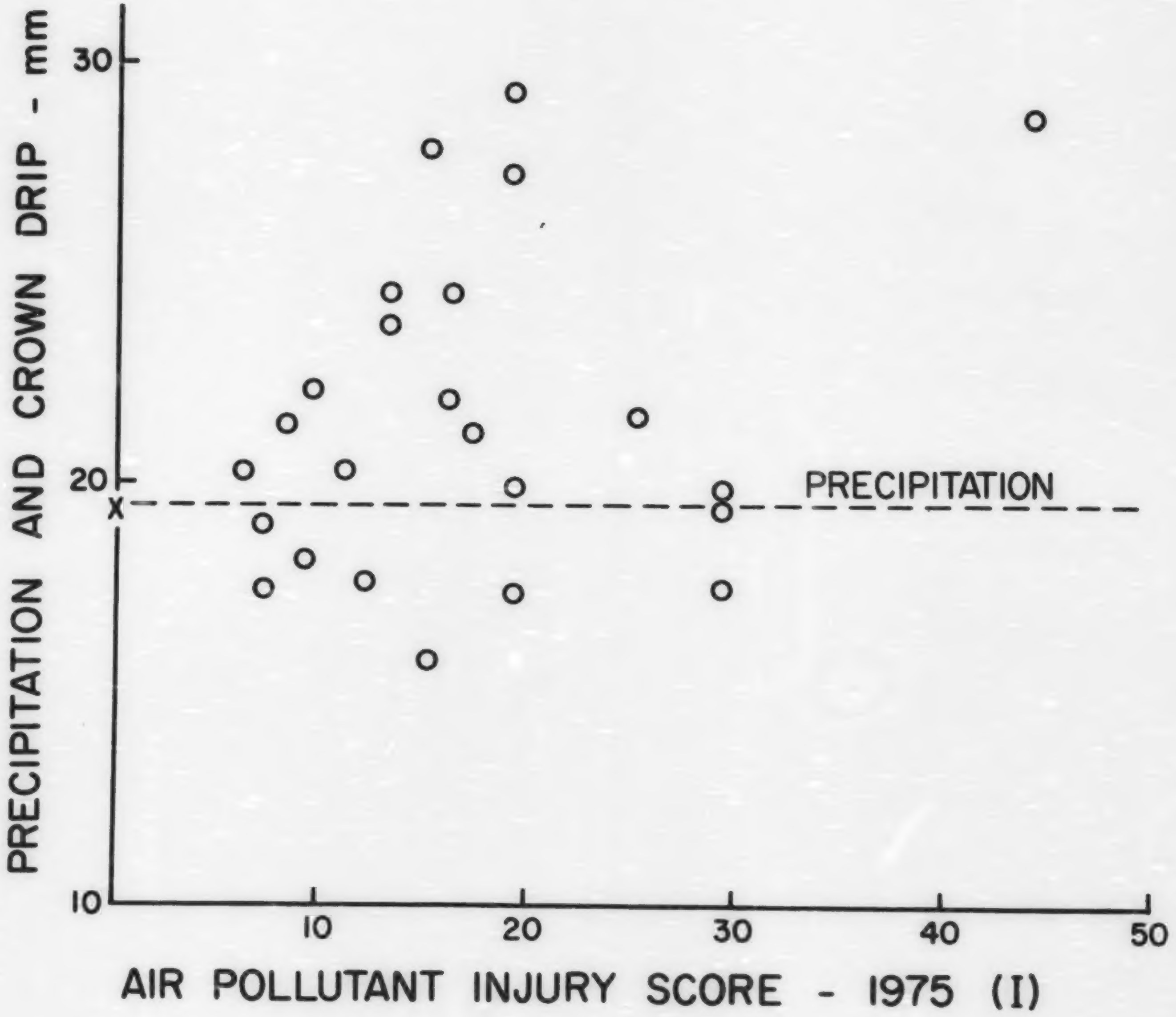


Figure 61. Precipitation and crown drip collected under 24 trees expressing various degrees of air pollutant injury. (Low score = high injury)

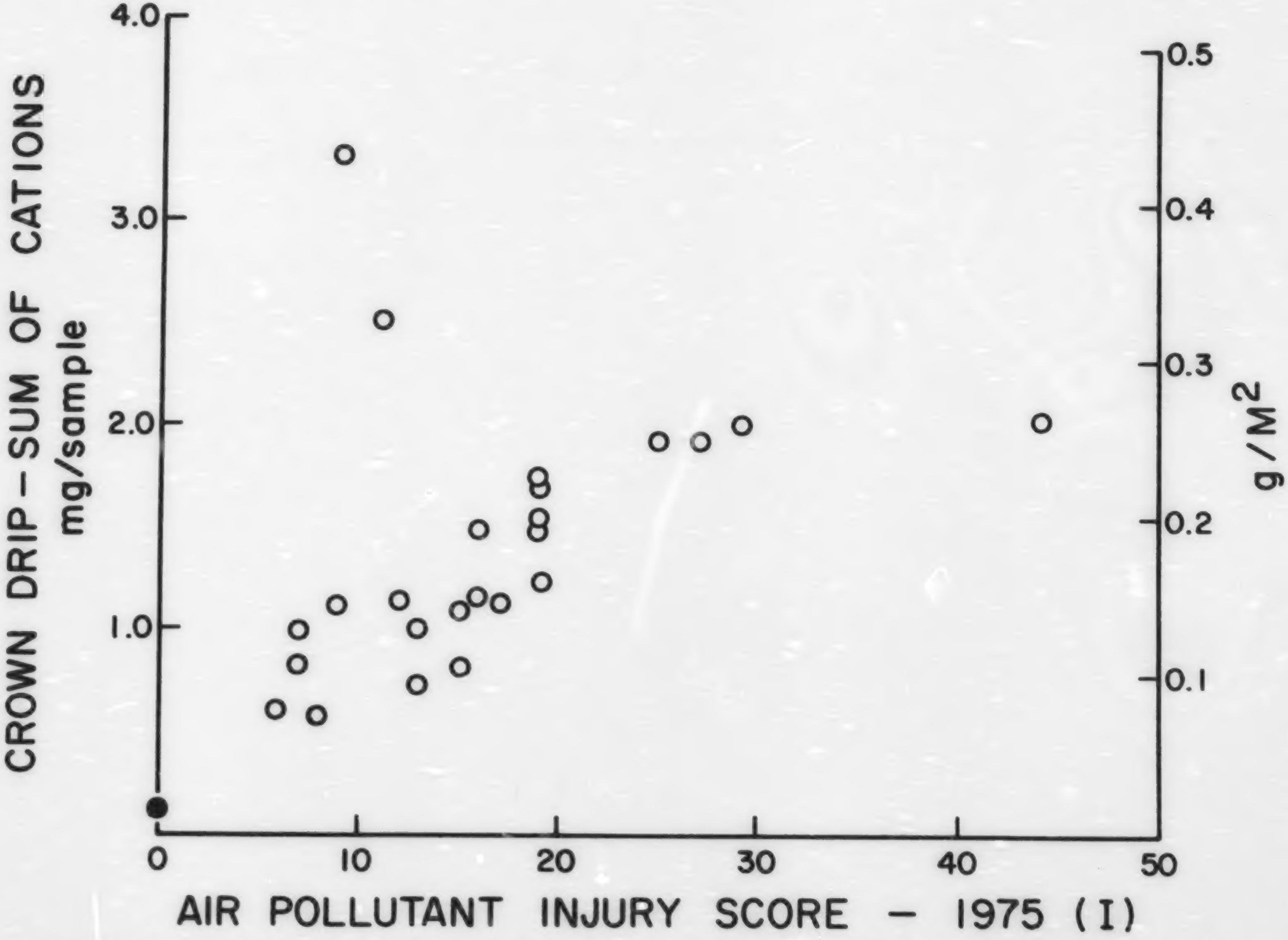


Figure 62. Cation content of crown drip water related to air pollutant score. (Low score = high injury).

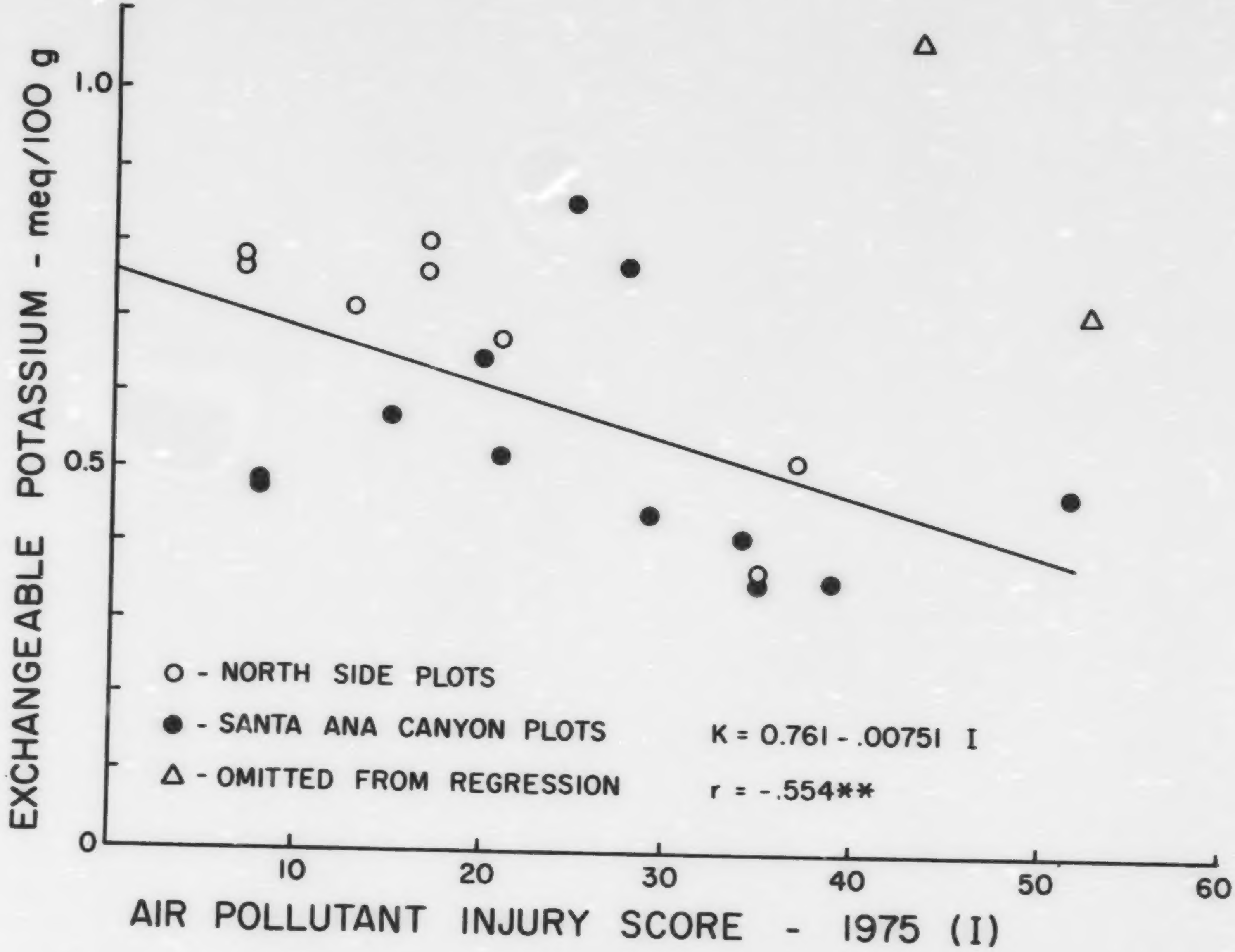


Figure 63. Relationship of potassium (k) content of soils to the air pollutant injury score on adjacent trees. (Low score = high injury).

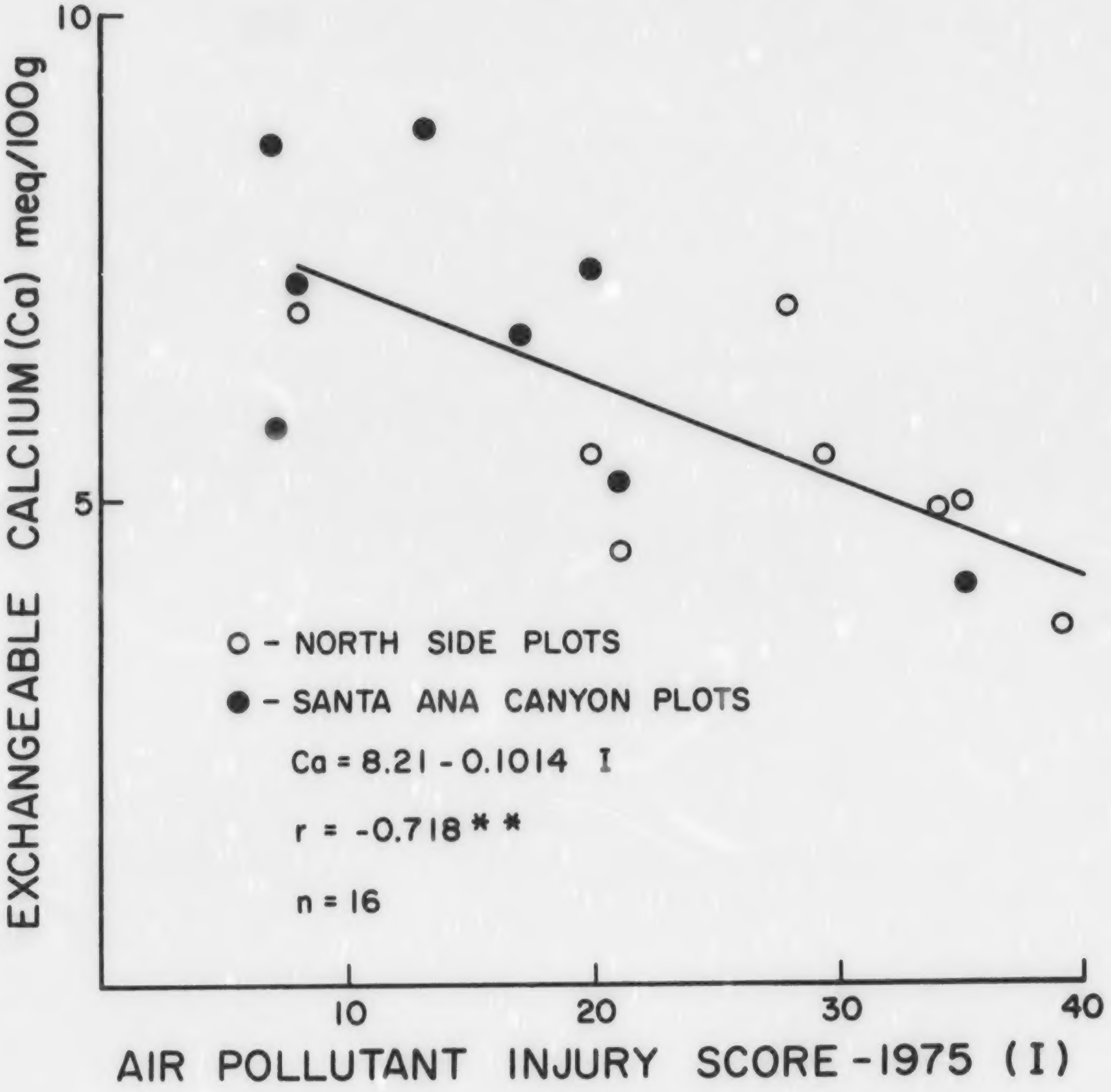


Figure 64. Relationship of calcium (Ca) content of soil to the air pollutant injury score on adjacent trees (Low score = high injury).

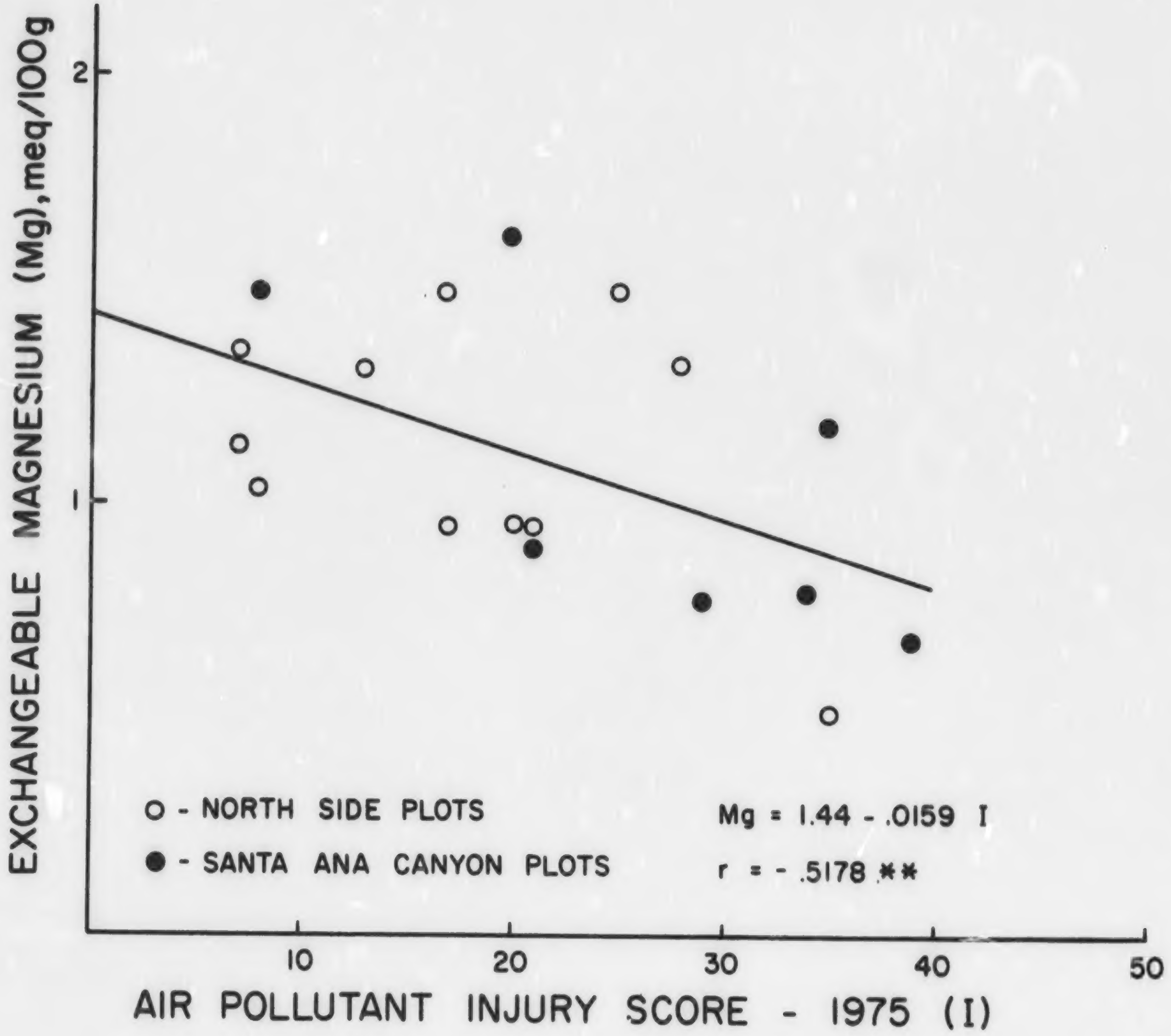


Figure 65. Relationship of magnesium (Mg) content of soil to the air pollutant injury score on adjacent trees (Low score = high injury).

A possible explanation of the apparent increase in exchangeable Ca, K, and Mg with increasing air pollutant injury may be found in the leaching of dead foliage on the forest floor resulting from air pollutant injury to the pine trees. As noted before, needle mortality and needle-fall are important consequences of air pollutant injury to yellow pines. Dead needles are subject to rapid loss of cations from leaching by precipitation. Apparently, these cations are added to the soil and fixed in exchangeable form in the first few inches of soil by the soils organic material. The excess cations added by this process would be expected to remain in the surface soil only temporarily; presumably after the death of the tree and the cessation of needle fall, excess cations would be leached into the deeper soil and eventually lost with deep percolation in wet years.

Soil samples were collected from the same trees being studied with respect to microarthropods, microorganisms, and seedling germination and establishment. Thus, it will be possible to integrate the soil information into those studies. In the absence of the integrated results, it is fair to say that critical nutrient levels have not yet been determined.

FOLIAGE LITTER DECOMPOSITION SUBSYSTEM: MICROBIAL ACTIVITY AND NUTRIENT CYCLING

Introduction

There is a continual turnover of tree biomass in the forest as old foliage, branches, and trees die and fall and others grow to replace them. Litter decomposition and nutrient cycling are the means by which the living forest recovers much of the nutrition incorporated in this organic matter. Recovery of these vital nutrients is the function of the vast populations of litter and soil microflora and microfauna. This portion of the overall study is directed toward determining the influence of oxidant air pollution on microfloral populations and leaf litter decomposition (primarily of ponderosa and Jeffrey pines). Although previous work in this field is relatively sparse, reviews are available (Dickinson and Pugh, 1974).

Research Objectives

Three major research approaches are being implemented in this subsystem study. They include the following:

1) To quantify needle litter decomposition in the field. This will help determine the degree to which oxidant air pollution affects (a) the quality of needles as substrates for decomposers and as sources of nutrients for cycling, and (b) the capacity of naturally occurring populations of litter microorganisms to decompose pine needle litter.

2) To characterize and quantify microfloral inhabitant populations of pine needles from needle elongation through decomposition on the forest floor. This will suggest effects of oxidant air pollution on decomposer communities and provide the basis for laboratory fumigation/decomposition experiments.

3) To conduct laboratory fumigation experiments on both fungal growth and needle decomposition. These are expected to clarify results obtained from field studies by eliminating such variables as moisture and temperature from consideration.

Materials and Methods

Needle Litter Decomposition in Natural Stands--
For this study, relatively isolated co-dominant and dominant trees were selected. Two each of the least and most oxidant-injured Jeffrey pine trees were selected on each of two sites. These sites were Holcomb Valley ("no" oxidant injury) and Camp Osceola ("moderate" oxidant injury).

Similar selections of ponderosa pines were made at Barton Flats ("moderate" oxidant injury) and Camp Oongo ("moderate-heavy" oxidant injury). These sites represent the range of oxidant injury to each species on the study plots in the SBNF. During the autumns of 1974-1976, freshly fallen litter was sampled randomly beneath each selected tree and subsamples of approximately 15 gm were made at random. One random 20-gm subsample from each tree per year was analyzed by Drs. Gersper and Arkley for nutrient content. An additional random sample was dried to 30 C, allowing calculation of a fresh/dry weight ratio for the entire sample. The remaining subsamples were placed in labeled nylon mesh (3 mm) envelopes (approximately 15 cm x 30 cm) and disbursed as related in Figure 66. Each arrow in Figure 66 represents similar treatments consisting of 5, 10, and 10 envelopes left in the field for one winter, one year, and two years, respectivley. The 1974 samples comprised the two-year experiment; the 1975 samples comprised the one-year and first one-winter experiments; and the 1976 samples comprised the second one-winter experiment. The first one-winter experiment was repeated, and the second involved the exchange of ponderosa and Jeffrey pine litter between their respective sites (Fig. 67). The rationale for this is explained in the following discussion.

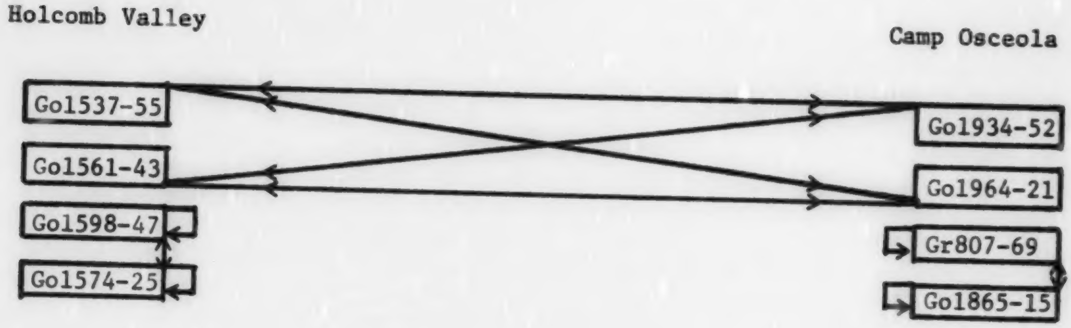
After each treatment was completed, envelopes were, or will be, retrieved. The needles will be (1) brushed lightly to remove excessive inorganic and fungal material; (2) dried to a constant weight at 30 C and weighed; (3) classified visually into categories of decay type; and (4) analyzed for percent content of N, P, K, Ca, and Mg. Percent change in weight and nutrient content are then calculated.

Decomposer Microorganism Populations on Pine Needles in Natural Stands Experiencing Different Oxidant Doses--

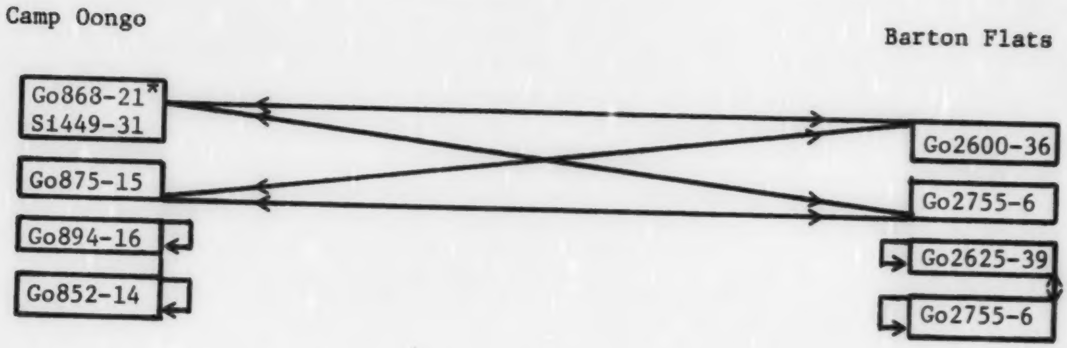
Oxidant air pollution may alter the rate of pine needle decomposition by affecting the composition of microbial populations on senescing and fallen needles. To study the succession of litter microorganisms, two lines of investigation were followed in the field. Microbial succession in living needles was determined by isolation of fungi from surface-sterilized needles of various ages, while succession in litter was determined by isolating fungi from surface-sterilized needles that were on the forest floor for varying periods of time.

Before litter fall in 1974-1976, one square meter of nylon mesh was placed approximately two-thirds of the crown radium out from the stem beneath each of the trees involved in the integrated field needle decomposition study. In 1974, four trees were tagged at each of two locations in the University of California Blodgett Experimental Forest, El Dorado County, California. They were tagged Gr 1-8, and each received a nylon mesh square prior to litter-fall in 1974 and 1975. In 1975, four Jeffrey and four ponderosa pines were selected for study and tagged Gr 9-16 on the Stanislaus National Forest, near Pinecrest, California. Each received mesh squares prior to litter-fall in 1975. It is felt that pine stands outside the SBNF must be considered for comparison in terms of air pollution impact. Having separated annual increments of litter-fall in this manner, we collected periodic samples of litter from these nets, surface-sterilized them, and incubated them on water agar in petri dishes. The

Pinus jeffreyi


Holcomb Valley
Camp Osceola
Go1537-55
Go1561-43
Go1598-47
Go1574-25
Go1934-52
Go1964-21
Gr807-69
Go1865-15

Pinus ponderosa


Camp Oongo
Barton Flats
Go868-21*
Si449-31
Go875-15
Go894-16
Go852-14
Go2600-36
Go2755-6
Go2625-39
Go2755-6

*1974 oxidant score (Go868 was killed by bark beetles and replaced in this study by Si449.)

Figure 66. Source and destination (tree tag-1976 oxidant score) of 960 decomposition study envelopes. Each arrow represents 30 envelopes and points from their source to their destination.

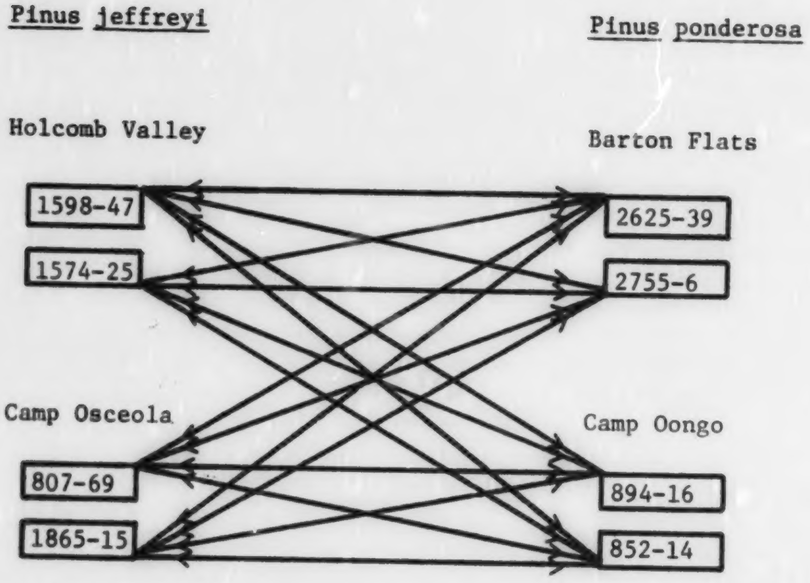


Figure 67. Source and destination (tree tag-1976 oxidant score) of 160 decomposition study envelopes. Each arrow represents 5 envelopes and points from their source to their destination.

diversity and populations of microorganisms were then recorded.

To determine the succession of microorganisms on living pine needles, the lowest healthy twigs on the north, south, east, and west sides of the stem were clipped not only from trees involved in the integrated field needle decomposition study, but also from trees at Blodgett and Pinecrest. The annual needle increments on each twig were separated in the field. A subsample of each increment was surface-sterilized and incubated on water agar in petri dishes. The diversity and populations of microorganisms were then recorded and analyzed.

Laboratory Tests of the Effect of Oxidant Dose on Decomposers and Decomposition--

This phase of the project is designed to determine how air pollution affects (1) growth and reproduction of microbial agents of litter decomposition, and (2) rates of needle decomposition by major microorganisms.

Two clear and twelve opaque plexiglass fumigation chambers were constructed and installed inside two walk-in Percival growth chambers on the Oxford Tract, UCB. These walk-in chambers have been renovated to permit control of light, temperature, and relative humidity. The plexiglass chambers were designed to permit control of ozone concentration, and are currently being calibrated and tested.

Species of fungi isolated from litter samples will be fumigated at a number of ozone concentrations. The fungus will be inoculated onto sterile pine needle sections placed on cellophane-covered cellulose agar in petri dishes (Eggins and Pugh, 1962). The effects of ozone will be quantified on such factors as (1) colony growth rate, (2) spore production, (3) spore germinability, and (4) cellulose decomposition.

Sterile litter from a variety of sources was inoculated by placement on wet humus from a variety of sources and fumigated to determine the effects of ozone on needle decomposition by natural complexes of decomposer microorganisms. Such fumigation experiments were designed to separate the direct effects of ozone on microbes from the effects of ozone on the suitability of a substrate for decomposition.

Results and Discussion

Needle Litter Decomposition in Natural Stands--

Quantification of integrated needle litter decomposition in the field has progressed. Data sets are complete for weight losses incurred by 160, 320, and 320 mesh litter envelopes over one winter, one year, and two years, respectively. The 32 treatments involved in each of these three experiments are diagrammed in Figure 66. Change in nutrient status (percent N, P, K, Ca, Mg) has been determined for a pooled sample from each of the 32 over-winter treatments. As Dr. Gersper's schedule permits, similar data on post-harvest chemical analysis will be obtained for the one- and two-year treatments.

Ponderosa pine litter lost more weight ($\alpha=.001$) during the first winter and the one- and two-year experiments than did Jeffrey pine litter. Within each species, available data shows greater weight loss on the site receiving the greatest oxidant air pollution dosage. Preliminary nutrient data available to date suggest that during the first over-winter experiment, ponderosa pine needles lost more P and K than did Jeffrey pine needles. In general, these data also showed a decline of N in Jeffrey pine needles but an increase of N in ponderosa pine needles. This increased N and decreased P and K may correspond to the greater fungal activity observed in ponderosa pine litter.

It is thought that the weight losses experienced over the winter of 1975/1976 were relatively light, probably reflecting the below-normal precipitation. The overwinter experiment currently in the field may provide more representative data and substantiate the trends observed to date. The sparse literature relevant to this point suggests that weight and nutrient losses by pine needle litter during its first winter on the ground are relatively great (Stark, 1972, 1973; Millar, 1974).

Because ponderosa pine sites may receive more precipitation than the Jeffrey pine sites, not only soil moisture data being collected by the soils group, but also precipitation, air temperature, and approximate oxidant-dosage estimates for the involved sites, will be used in the interpretation of data collected. Also, litter of each species has been disbursed to sites of the opposite species for the winter of 1976/1977. Weight and nutrient loss data from this experiment will help clarify the effects of site and litter specie on decomposition.

Decomposer Microorganism Populations on Pine Needles in Natural Stands Experiencing Different Oxidant Doses--

One complete experiment during late summer of 1975 has provided information on microbial succession in pine foliage in the SBNF, Blodgett Forest, and the Stanislaus NF. Data from a similar experiment in the SBNF during spring, 1976, will be analyzed shortly. One additional complete experiment of this type is planned for early spring, 1977. In this experiment, it is hoped that nutrient status will be determined by Dr. Gersper's group for each annual increment of foliage. Results of the first experiment are tentative, requiring further analysis and confirmation. Collection of data on microbial succession in litter continues. The value of the data increases from each successive sampling; there are now four annual increments of litter-fall separated (except where nets have been vandalized) in the SBNF. All data collected from these studies will be interpreted in the light of existing soil moisture, precipitation, air temperature, and other site data, as well as from oxidant dosage information.

Through the study of annual increments of living foliage and stratified litter, successions of microfloral populations are being determined for individual trees representing plots and regions impacted by varying amounts of smog. Comparisons among these population successions will help explain patterns in (1) litter decomposition and (2) the incidence of fungus-caused damping-off of pine seeds and seedlings (under study by the seedling establishment investigators). Species of fungi for which population data have been collected, to date, include phycomycetes, ascomycetes, basidiomycetes, and fungi imperfecti. A method for the culture of fungi on microscope slides has been employed forthe grouping and identification of important isolates (Riddell, 1950).

Laboratory Tests of the Effect of Oxidant Dose on Decomposers and Decomposition--

The clear plexiglass chambers and ozone detection equipment have only recently become operational. Though no data are yet available, these studies are planned and will be underway very shortly.

FOLIAGE LITTER DECOMPOSITION SUBSYSTEM: MICROARTHROPOD ACTIVITY

Introduction

Natural Role of Microarthropods--

Litter microarthropods form an important, if rather inconspicuous, component of the forest ecosystem. Therefore, it is necessary to evaluate the effects of potentially disruptive environmental contaminants, e.g., oxidant air pollutants, on these abundant arthropods. The pine needles, twigs, and other organic materials that make up the forest floor and the underlying upper layers of mineral soil contain a complex and diverse community of small (often less than 2-3 mm) animals. They belong to the phylum Arthropoda, which includes insects, mites, spiders, centipedes, and a variety of other less well known animals; taken together, these can be termed "litter microarthropods." They can occur in very large numbers, with population estimates in pine forest soils ranging from 102,000/m^2 in Tennessee (Crossley and Bohnsack, 1960), to 200,739/m^2 in California (Price, 1973).

The primary role of litter and soil microarthropods in conjunction with the soil microflora (fungi, actinomycetes, and bacteria) is to decompose and reduce plant and animal organic residues which fall to the forest floor (Edwards *et al*., 1970; Millar, 1974). They can contribute directly to the decomposition process by mechanically breaking down organic materials such as pine needles into smaller fragments. The activity and movement of microarthropods help to reduce these fragments further into humic substances and then to mix them and other breakdown products with the mineral soil below. These processes make the nutrients contained in the undecomposed organic material available for use by other plants and animals in the ecosystem. Furthermore, these disintegrating and reducing activities can increase the surface area of organic material and create microhabitats and substrates that are more easily attacked by soil fungi and bacteria. In turn, these microflora chemically decompose and change the organic residues, which benefits the microarthropods. Thus, both directly and indirectly, through decomposition, mechanical mixing, and by complex interactions with soil microflora, soil microarthropods affect overall soil fertility and nutrient cycling.

At the same time, species composition and abundance of litter microarthropods can be influenced by various soil and litter properties. These include the quantity and quality of the organic litter, its accumulation rate, soil water availability, and the pH of the soil. Litter microarthropods are also affected by the biological components of the soil, including microflora. Chemicals released by the action of soil fungi may inhibit or enhance litter microarthropods; some of these arthropods feed on, and hence are dependent on, certain fungi. From a long-term standpoint, these complex feedback interrelationships between litter microarthropods and the physical and biological attributes of the soil can significantly affect forest succession. They accomplish this through natural seed bed preparation, seed germination success, seedling survival, and the basic role of decomposition.

Stable forest ecosystems are generally considered to have a relatively constant rate of litter production (Burgess, 1967). Any factor that could affect this balance warrants investigation. Disturbances could involve not only changes in the rate and amount of litter fall, but also the quality of the organic matter itself. In addition, other factors are involved such as the composition and amounts of dissolved organic matter in rain water passing through the canopy. Such changes could take several years as ponderosa or Jeffrey pine gradually weaken due to continued exposure to oxidants or they could be accelerated by disease, bark beetles, or an interaction of factors. Under natural conditions, the dead trees themselves ultimately fall to the forest floor and are decomposed.

Research Objectives

The response of litter microarthropods and other components of the forest floor to these changed conditions may influence the nature of forest regeneration through nutrient availability. Thus overall objectives of this study were to determine the (primarily indirect) effects of photochemical air pollution on the litter microarthropod component of the ecosystem, and to evaluate the effects of this component on the rest of the system. The specific objectives are as follows:

1) To determine species abundance and diversity in the forest floor under selected individual trees.

2) To relate these population characteristics to soil and litter properties.

3) To determine how photochemical air pollutants influence litter microarthropod populations: through their effect (a) on litter quantity and quality, and (b) on microbial activity.

4) To relate litter microarthropod populations with soil microbial populations under selected individual trees: (a) by correlating microarthropod and microbial species composition and relative densities; and (b) by determining the succession of soil microarthropods and microflora in the decomposition of forest litter and their effect on gross decomposition rates.

5) To determine and compare characteristics of ecological disruptions of litter microarthropods caused by oxidant air pollutants at undisturbed (natural) sites and at sites of disruptions caused by other factors, e.g., pesticides, fire, and logging.

6) To identify specific components of the litter microarthropod community as indicators of an ecosystem disrupted by oxidant

air pollutants.

Methods and Materials

Field Sampling Technique--

Plots and individual sample trees were selected primarily on the basis of oxidant injury ratings in an attempt to compare them at different oxidant levels. To minimize possible sources of variation, an attempt (largely unsuccessful) was made to choose trees that were isolated and undisturbed (other than by oxidant air pollutants), and that were relatively uninfluenced by adjacent trees. In addition, an effort was made to work with trees, at least within plot, that were of similar size and age. Table 45 shows the vegetation plots, trees, and dates on which they were sampled.

Samples were taken at six-week intervals with a rectangular shaped soil corer 32.26 cm^2 (5 sq. in.) in area. Some variation in time occurred due to snow and other weather conditions. Ten cores per tree were taken on each sample date and, where appropriate, the different forest floor layers (litter, fermentation, humus) and the top 0-5 cm of mineral soil were measured and stored separately for individual extraction. The forest floor beneath each sample tree was divided into eight quadrants based on cardinal direction. The exact dimensions depended on crown size, ground cover, and disturbances of the forest floor. Samples were taken by randomly selecting the quadrant and specific direction from the tree bole; the location of each individual core was mapped as precisely as possible using the angle (from N, 0-360) and the distance from the bole. (This sampling is directly coordinated with the "Litter Decomposition and Nutrient Cycling" subproject.)

Laboratory Analysis Procedure--

All cores taken in the field were stored at low temperatures until extraction. Microarthropods were extracted from the soil using a high heat gradient modified Berlese funnel system (Price, 1973). This system uses a combination of heat, light, and drying action on the individual soil samples. It drives microarthropods from the soil core through steep-walled plastic funnels sprayed with a dry silicone lubricant, and then into alcohol-filled vials where they are preserved for later analysis and counting. The temperature in the funnel units was controlled by a voltage regulator and was increased gradually from an initial temperature of 32 C. This was done to avoid excessively rapid heating and drying of the soil cores, which could result in microarthropods being killed in place, rather than being driven into the alcohol vial. Each core was extracted in the system for a minimum of three days.

Data Capture and Analysis--

Through June, 1976, all field samples have been extracted, identified, and counted. All data have been put into the information system, data capture programs have been run, and data have been verified and corrected. Programs are being written to combine data for different species into predator, decomposer, and other groups, and to combine different soil horizons as needed. Also, programs are being developed to perform the required statistical analyses and for output of corrected, fixed format

TABLE 45. SAMPLE DATES FOR SOIL MICROARTHROPODS BENEATH TREES ON ESTABLISHED VEGETATION PLOTS. SAN BERNARDINO NATIONAL FOREST, 1973-1975.

				1973			1974						1975
Plot	Tree no.	Species	Smog rating	Aug 16	Oct 4	Nov 27	Apr 2	May 21	Jul 1	Aug 19	Oct 1	Nov 15	Aug 8
SV2	753GO	JP	14	X	X	X	X	X	X	X	X	X	X
SV2	785GO	JP	12	X	X	X	X	X	X	X	X	X	X
NEGV	614GO	JP	24	X	X	X	X	X	X	X	X	X	X
NEGV	618GO	JP	26	X	X	X	X	X	X	X	X	X	X
BP	394GO	PP	29			X	X	X	X	X	X	X	X
BP	397GO	PP	9			X	X	X	X	X	X	X	X
COO	868GO	PP	24								X	X	X
COO	890GO	PP	10								X	X	X
CAO	1865GO	JP	15								X	X	X
CAO	806GR	JP	23								X	X	X
SF	1234GO	PP	22								X	X	X
SF	1245GO	PP	9								X	X	X
SCR	1706GO	PP	23										X
SCR	1729GO	PP	7										X

data decks. This work will be completed under the contract for 1976-77.

Results and Discussion

A list of specimens collected during the initial phases of the study is given in Appendix L. The systematics of many of these groups, especially the Acarina, are poorly understood, and at this point many groups have not been identified beyond their family level.

Data analyses have been limited since the effort to date has been directed primarily toward creation of error-free and complete data files. However, trends can been seen by examining the mean values of total microarthropods per sample collected under the 6 trees sampled from 1973 to 1975 (plots SV2, NEGV, BP). Three of these trees were heavily damaged (range 9-14) by pollutants, while the others were lightly damaged (range 24-29). Figure 68. plots the comparative means of total microarthropods per sample in the organic layer of heavily and lightly damaged trees. Considerable variation by date is evident, but at every date fewer microarthropods were collected in samples under damaged trees. It appears that populations are generally lowest during the July-August period of any given year, suggesting that moisture and/or temperature have an effect. Only one sample was taken during 1975, so it is not possible to tell if the high populations of August, 1975 were a continuing trend from those shown for November, 1974. Conclusions can only be tentative because the effect of the plots, sample depths, and between-sample variation have not yet been analyzed for this group of samples.

An analysis has also been conducted for four plots, each with one damaged and undamaged tree. The sampling dates were October 1, and November 15, 1974. The variable in this case was mean microarthropod density, and the means are given in Table 46. Analysis of variance by plot, tree smog-damaged level, and date showed that microarthropod density was significantly different between two dates (.005 level) and significantly different among plots (.05 level). Individual means compared in pairs with Tukey's HSD test showed that only in one plot (BP) on one date 11/15/74 was microarthropod density significantly greater in the undamaged tree compared to the damaged one. Among the four plots, three had moderate smog concentrations (BP, CAO, COO) and one had heavy smog concentration (SF). There were no significant differences in density for all trees on the first date, and none for heavily damaged trees on the second date. However, on the second date, the lightly damaged tree in BP had a significantly higher density (to .05 level) than the lightly damaged trees in COO and SF on that date.

From the analyses completed up to this point, it appears that date, plot, smog damage, moisture, and temperature are factors in establishing microarthropod populations. Much more extensive data collection would be required to meet all research objectives named. The difficulty of coupling arthropod data from such small plots with the forest stand succession modeling strategy on a much larger scale augers against the continuation of data collection efforts. Further analysis of the data may isolate some critical factors and determine if some groups of microarthropods are permanently affected.

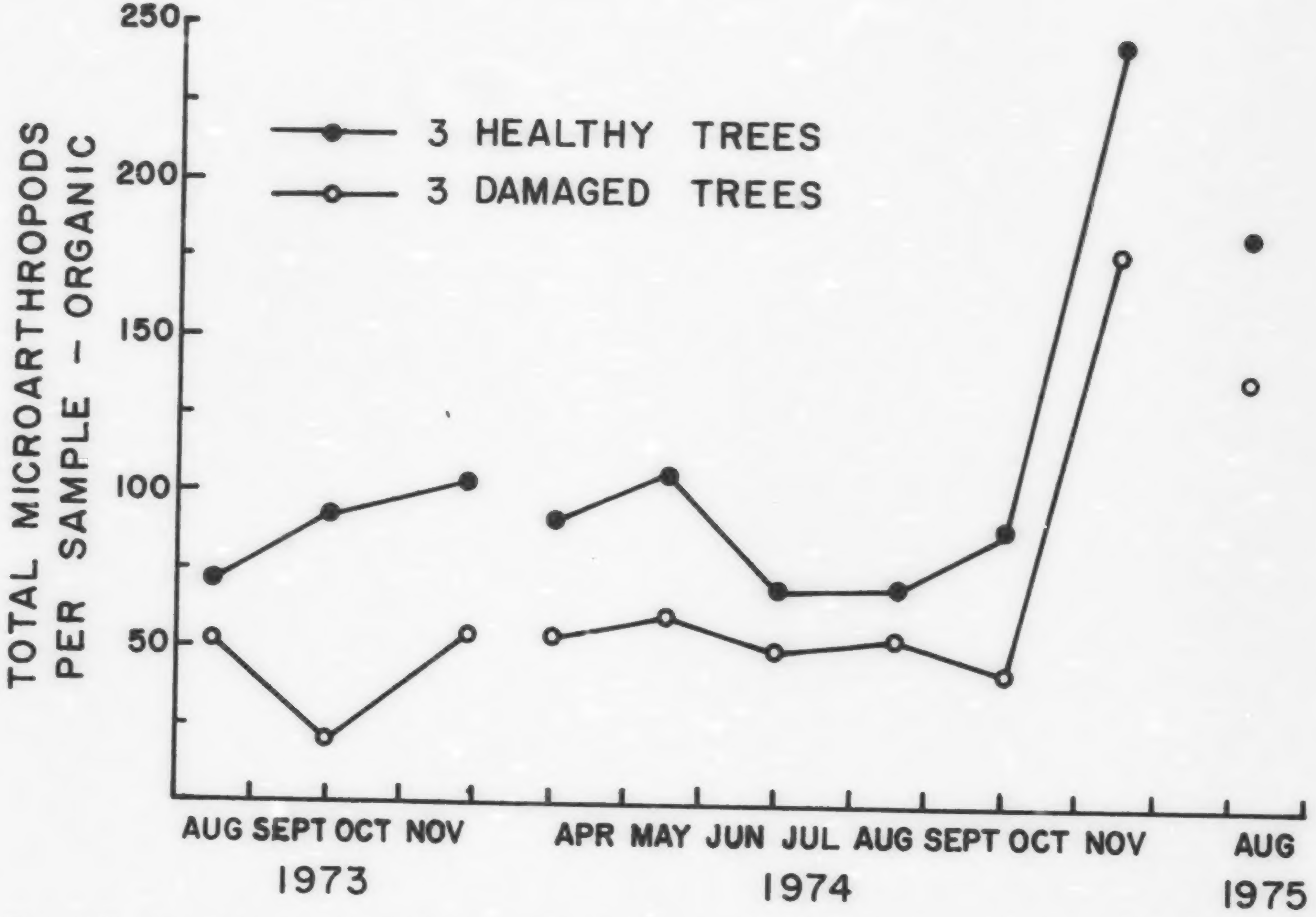


Figure 68. Total microarthropods per sample (organic horizon) collected under 6 trees from 1973 to 1975, San Bernardino National Forest.

TABLE 46. MEAN MICROARTHROPODS PER DECIMETER OF SOIL CORE FOR ALL LAYERS ON FOUR PLOTS FOR TWO SAMPLE DATES, FALL, 1974, SAN BERNARDINO NATIONAL FOREST.

		Plots			
	Tree	BP (mod. smog)	CAO (mod. smog)	COO (mod. smog)	SF (severe smog)
Date[‡/] 10/1/74	Heavy Damage	92	130	124	110
	Light Damage	141	134	107	73
Date[‡/] 11/15/74	Heavy Damage	387[*/]	416	357	428
	Light Damage	627[*,+/]	455	368[+/]	307[+/]

[*/] Significantly different at .05 level.

[+/] BP significantly different at .05 level from COO and SF.

[‡/] Densities between dates significantly different to .005 level.

WOODY LITTER DECOMPOSITON SUBSYSTEM

Introduction

Rationale for the Study--

Trees chronically exposed to oxidant pollutants lose photosynthetic capacity. One possible effect of this may be an alteration of woody tissues and a change in the wood's resistance to attack by decay fungi. Such altered resistance may affect litter accumulation and nutrient cycling, in addition to having various other effects on the forest floor. On the other hand, direct exposure of decay fungi on the forest floor to air pollutants may alter their growth rate or their ability to decay wood, which would produce similar effects on litter accumulation and nutrient cycling. Collection sites for this subproject were coordinated with other projects dealing with soil, litter, and assoicated fungi and insects. The overall objective of this study was to determine whether exposure to air pollutants alters wood decay resistance or the activity of decay fungi.

Research Objectives

The specific objectives for this subproject for the past year were as follows:

1) To analyze the results of a soil-block test testing the decay resistance of ponderosa pine wood grown under different levels of exposure to air pollutants.

2) To determine the effect of exposure to various levels of ozone on the decay capacity of fungi isolated from the study site and some standard wood decay fungi.

3) To determine the effect of exposure to various levels of ozone on the growth rate of fungi isolated from the study site and some standard wood decay fungi.

This report summarizes the results of attempts to isolate decay fungi from woody litter on the study site and of experimentation to determine possible effects of oxidant exposure on the susceptibility of wood produced under such exposure to attack by wood decay fungi.

Methods and Materials

Identification of the Kinds of Fungus Decomposers of Woody Litter--

Pieces of large ponderosa pine wood lying on the ground were collected during spring, summer, and fall of 1973 from sites representing the full range of long-term exposures. Isolates were screened for ability to cause weight loss in wood by exposing wood blocks to actively growing agar cultures. Decay resistance and rate of decay were measured by a standard soil-block method (American Society for Testing and Materials, 1973). For the most active decayers of the fungi isolated, decay rate and hyphal growth rate were measured in the laboratory under conditions of high and low ozone concentration.

Testing Decay Susceptibility of Sapwood from Trees with Different Amounts of Oxidant Injury--

Four small ponderosa pine trees were felled in May, 1974, in the SBNF adjacent to Dogwood and Tunnel II, two established study plots rated as "moderate" and "slight" oxidant exposure sites, respectively. Two trees representative of both high and low degrees of tree damage from oxidant exposure were chosen from each site. Several feet of the butt portion of each stem were collected as sample material. After ring counts and measurements were made, specimens 2.5 x 2.5 x 0.9 cm (in the grain direction) were machined. These specimen blocks were exposed for 12 weeks to decay fungi in a soil-block test (American Society for Testing and Materials, 1973) using the standard test fungi *Poria monticola*, *Lenzites trabea*, and *Polyporus versicolor*, along with two decay fungi isolated from the SBNF sampling sites. The white-rot fungus, *Polyporus versicolor*, is not normally used when testing coniferous woods because white-rot fungi rarely attack coniferous wood in service. Since both the San Bernardino isolates appeared to be white-rot fungi, however, *P. versicolor* was used for comparison as a known, vigorous, white-rotting wood destroyer.

Results and Discussion

Degree of Completion of Research Objectives--

Objective 1 was satisfied and the results are reported here. Objectives 2 and 3 were not achieved because of delays in completing modifications of the ozone exposure chambers necessary to undertake this work; such modifications are being carried out by one of the other subprojects.

Identification of the Kinds of Fungus Decomposers of Woody Litter--

Eleven of the fungi isolated from woody litter have been shown by general screening to be wood-destroying organisms; microscopic examination has certified that at least five are definitely decay fungi. Superficial examination of the decay suggests that all wood-destroying isolates may be white-rot fungi. This is surprising, since most decomposers of coniferous wood in soil contact are brown-rot fungi.

Decay Susceptibility of Sapwood from Trees with Different Amounts of Oxidant Injury--

Results of the soil-block test are shown in Table 47: descriptive data on sample trees are shown in Table 48, which indicate that the majority of sample material taken consisted of sapwood. Sapwood of all tree species is considered to have no resistance to decay in service. However, since oxidant damage to trees in this area dates back no more than approximately 25 years, use of heartwood for the tests would have involved tissue produced before the onset of oxidant impact, and was therefore not of interest. The test became one of comparing possible differences in sapwood susceptibility, instead of one of comparing possible differences in heartwood decay resistance. As shown in Table 47, no meaningful differences in decay susceptibility were found in sapwood produced under various conditions of oxidant impact for any fungi employed. Weight losses caused by the two San Bernardino isolates were substantially lower than those produced by any of the recognized products destroyers. It is not unusual to find that field- and tree-isolated decay fungi perform poorly in a soil-block test as compared with decay fungi isolated from decaying wood in service. In our screening tests, these two San Bernardino isolates have consistently produced the highest weight losses of any of the decay fungal isolates obtained from the San Bernardino sites.

One sample tree contained sufficient heartwood to include a small test of heartwood decay resistance in the experiments. As shown in Table 47, it demonstrated moderate decay resistance (American Society for Testing and Materials, 1973) to P. monticola and was highly resistant to the other fungi. This is considerably greater resistance than that reported by Clark (1957) in comprehensive tests on a number of western coniferous heartwoods. He reported average weight losses for ponderosa pine heartwood of 53% with P. monticola and 19% with L. trabea. However, the values reported in Table 47 refer to a sample from a single tree and are within the range of variation reported by Clark. Furthermore, since the heartwood included in the present work was formed 49 to 55 years before felling, any variations in data are presumed not to involve effects of oxidant exposure.

The severity of damage to the tree, as noted by external symptoms, appears to be recorded in the growth of the tree by progressively decreasing thickness of annual increments (Table 48).

The difficulty of incorporating the results of these detailed studies into the forest stand level modeling strategy selected for the project may lower the priority level of this subsystem as it is now defined.

TABLE 47. RESULTS OF SOIL-BLOCK TEST ON WOOD GROWN UNDER VARIOUS OXIDANT EXPOSURES.

	Sapwood				Heartwood
	Moderate oxidant exposure site (Near Dogwood study plot - Index 17)		Slight oxidant exposure site (Near Tunnel II study plot - Index 25)		Slight oxidant exposure site (Near Tunnel II study plot - Index 25)
Test parameter	Slightly damaged Tree-rating 24[*]	Very severely damaged Tree-rating 8	Tree with no visible injury Tree-rating 39	Severely damaged Tree-rating 9	Severely damaged Tree-rating 9
Weight loss (%) from fungi:[+]					
Poria monticola	68.1	68.0	69.6	68.8	32.6
Lenzites trabea	63.7	66.8	67.5	64.4	+ 0.3
Polyporus versicolor	39.6	34.1[‡]	34.0	35.3	1.4
SB #1[§]	21.6	22.6	16.4	10.5	0.5
SB #2[§]	26.2	23.8	20.5	21.7	1.6
Range in approximate age (yrs) of tissue in decay sample blocks	4-11	8-27	9-22	14-32	49-55

[*] Tree smog rating determined by John Zorich according to rating scheme developed by Paul Miller

[+] Sample size for each item of data was 10, except for one (see [‡] below)

[‡] Sample size for this item of data was 9

[§] Isolated from large litter on study plots in San Bernardino National Forest

TABLE 48. DESCRIPTION OF SAMPLE TREES.

	Moderate oxidant exposure site (Near Dogwood study plot - Index 17)		Slight oxidant exposure site (Near Tunnel II study plot - Index 25)	
	Slightly damaged Tree-rating 24[*/]	Very Severely damaged Tree - rating 8	Tree with no visible injury Tree - rating 39	Severely damaged Tree - rating 9
DBH (in)	8	8	11	9.5
Total age (yrs)	25	33	66	60
Years to heartwood	no heartwood	29	54	49
Number of rings per 1" intervals from cambium to pith				
First 1"	7	19	16	28
Second 1"	6	6	21	14
Third 1"	11	5	17	9
Fourth 1"	1 (to pith)	3 (to pith)	6	6
Fifth 1"			6 (to pith)	3 (to pith)

[*/] Tree smog rating determined by John Zorich according to rating scheme developed by Paul Miller

SMALL MAMMAL POPULATION DYNAMICS SUBSYSTEM

Introduction

Wildlife species form an important component of all forest ecosystems. As consumers, for example, wildlife may have a major influence on forest plant succession patterns (Lawrence, 1958; Hooven, 1969). Changes in wildlife abundance or species mix induced by direct or indirect effects of oxidant air pollution potentially may affect forest plant succession.

The overall objective of this wildlife study has been to describe the terrestrial vertebrate community within this mixed conifer forest, particularly in relation to ponderosa pine, Jeffrey pine, and other forest vegetation. We have attempted to describe (1) the effects of terrestrial vertebrates upon this forest and (2) the effects of photochemical air pollution on the vertebrate community. Neither time nor resources were available to study all vertebrates in detail. It was decided to emphasize only the common small mammals and the gray squirrel. Small mammals were selected for detailed study because they are reported to exert major effects on the ecology of many conifer forests and because their relatively limited range of travel makes them more subject to the air pollutant dose and fluctuation of food supply at any given location.

Literature Review--

Small mammals commonly consume a major portion of tree and shrub seed crops in western forest. In this manner they exert a major influence upon seedling establishment and, hence, potentially upon forest successional patterns (Moore, 1940; Smith and Aldous, 1947; Lawrence, 1958; Gashwiler, 1959; and Black, 1969). Additionally, small mammal populations respond markedly to habitat alteration, particularly to vegetation and soil changes (Hagar, 1960; Vohs, 1974). Third, small mammals are one of the least difficult groups of vertebrates to study, and a modest body of literature exists on them in conifer forests (see reviews by Black, 1969, 1974).

Materials and Methods

Field work began in the summer of 1972, and was restricted largely to the summer period. As is the case in most wildlife studies, inventory was the first step. We prepared preliminary lists of the vertebrates found in the study area (White and Kolb, 1973) based upon observations and census, literature review, and consultation with experts.

Census of small mammal populations was conducted in the summers of 1972, 1973, and 1974, using standard mouse and rat snap-trap procedures (Calhoun, 1959). Trapping in 1972 occurred only on the 6 original plots (Kolb and White, 1974). In 1973 and 1974 trapping occurred on an expanded network of 18 plots. A total of 830 small mammals was captured in the three years.

One objective of these trapping censuses was to determine the species inhabiting the study plots and to estimate the population density patterns from plot-to-plot and from year-to-year. Partial results of these efforts were presented in Kolb and White (1974). Each specimen was initially preserved by freezing. Later specimens were thawed and dissected, and data on sex, age, general health, and reproductive conditions were recorded. Reproductive tracts, stomachs, parasites, and skulls (for age verification) were preserved for subsequent examination.

The western gray squirrel is too large to be studied by snap-trapping; nevertheless, gray squirrels were studied because they feed heavily upon conifer and oak seeds. They represent the largest source of loss of ponderosa and Jeffrey pine seed in this forest. The goal of this work has been to measure the extent of gray squirrel feeding upon ponderosa and Jeffrey pine seed crops.

Small Mammal Trapping--

In the three-year trapping period, a total of 17 species of small mammals was caught (Table 49). The dominant genus in this small mammal community was the deer mouse, which made up 54% of the total catch. The white-footed deer mouse alone represented 43.7% of the total catch, accompanied by noticeably fewer brush mice, pinyon mice, and California mice. Other common small mammals on the study plots are the dusky-footed woodrat, chipmunks (Merriam and lodgepole), the golden-mantled ground squirrel, and the Botta pocket gopher. Pocket gopher numbers are markedly under represented in Table 1 because they are not vulnerable to the standard snap-trap, and minimal efforts were made to sample them in proportion to their occurrence. Numbers of western gray squirrel, northern flying squirrel, and ornate shrew also are under represented for the same reasons.

There was considerable variation in the number of small mammals captured year-to-year and from one plot to another (Fig. 69). Overall, the most were captured in 1974, and the fewest were captured in 1973. Much of the fluctuation can be accounted for by changes in the numbers of deer mice, whose populations characteristically fluctuate dramatically from season-to-season and from year-to-year (Hooven, 1969).

The paucity of larger species in 1972, including the dusky-footed woodrat and golden-mantled ground squirrel, was largely a result of using only small museum special (mouse) traps during this first trap-year. The marked increase of both species in 1973 and 1974 is coincident with additional use of rat traps.

Figure 70 presents a comparison of the proportions of the catch on the study plots of deer mice, chipmunks, golden-mantled ground squirrels, and other species, with the results of similar trapping programs on three other yellow pine forest areas in California. These comparisons are made because of the lack of control plots in this current study. These three studies represent the best comparisons for California that exist in the

TABLE 49. COMPOSITION OF THE TOTAL SMALL MAMMAL CATCH ON THE STUDY PLOT, 1972 - 1974.

Species	1972		1973		1974		Composite	
	Number caught	% of catch	Number caught	% of catch	Number caught	% of catch	Number caught	% of catch
White-footed deer mouse (Peromyscus maniculntus	16	19.3	23	24.7	324	49.5	363	43.7
Dusky-footed woodrat (Neotoma fuscipes)	5	6.0	13	14.0	78	11.9	96	11.6
Merriam chipmunk (Eutamias merriami)	19	22.9	12	12.9	36	5.5	67	8.1
Golden-mantled ground squirrel (Callospermophilus lateralis)	2	2.4	13	14.0	36	5.5	51	6.1
Brush mouse (Peromyscus boylii)	28	33.7	9	9.7	4	.6	41	4.9
Botta pocket gopher (Thomomys bottae)					37	5.7	37	4.5
Unidentified chipmunks*			5	5.4	29	4.4	34	4.1
Unidentified deer mice*			1	1.1	31	4.7	32	3.9
Lodgepole chipmunk (Eutamias speciosus)	3	3.6	3	3.2	22	3.4	28	3.4
California meadow mouse (Microtus californicus)	7	8.4	7	7.5	9	1.4	23	3.8
Beechey ground squirrel (Spermophilus beecheyi)			1	1.1	20	3.1	21	2.5

TABLE 49. CONTINUED

Species	1972		1973		1974		Composite	
	Number caught	% of catch	Number caught	% of catch	Number caught	% of catch	Number caught	% of catch
Western harvest mouse (*Reithrodontomys megalotus*)			1	1.1	12	1.8	13	1.6
Pinyon mouse (*Peromyscus truei*)	1	1.2	1	1.1	4	.6	6	.7
California mouse (*Peromyscus californicus*)					6	.9	6	.7
Western gray squirrel (*Sciurus grisceus*)			1	1.1	3	.5	4	.5
Northern flying squirrel (*Glaucomys sabrinus*)			3	3.2			3	.4
California pocket mouse (*Perognathus californicus*)					2	.3	2	.2
Pacific kangaroo rat (*Dipodomys agilis*)	1	1.2			1	.2	2	.2
Ornate shrew (*Sorex ornatus*)	1	1.2					1	.1
TOTALS	83	100.0	93	100.0	654	100.0	830	100.0

*Species of these individuals still being determined.

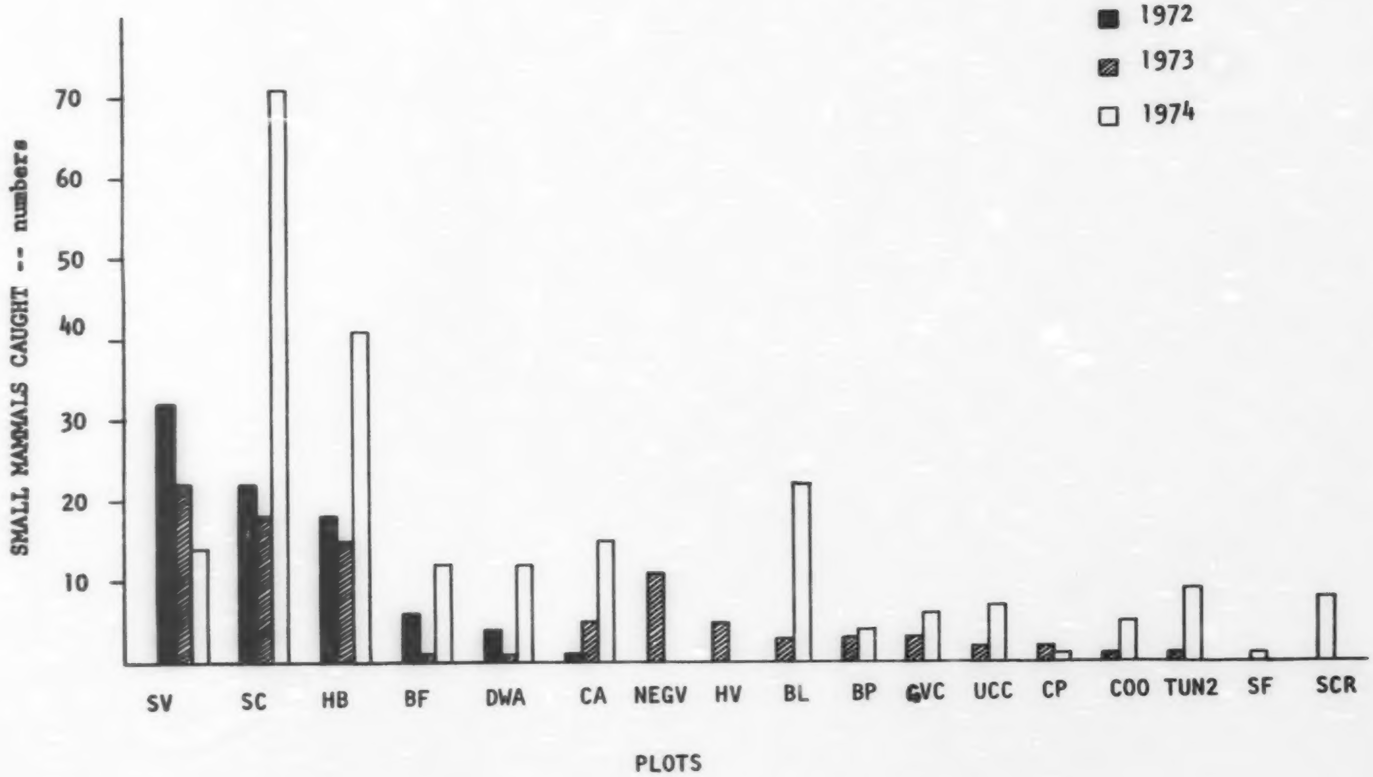
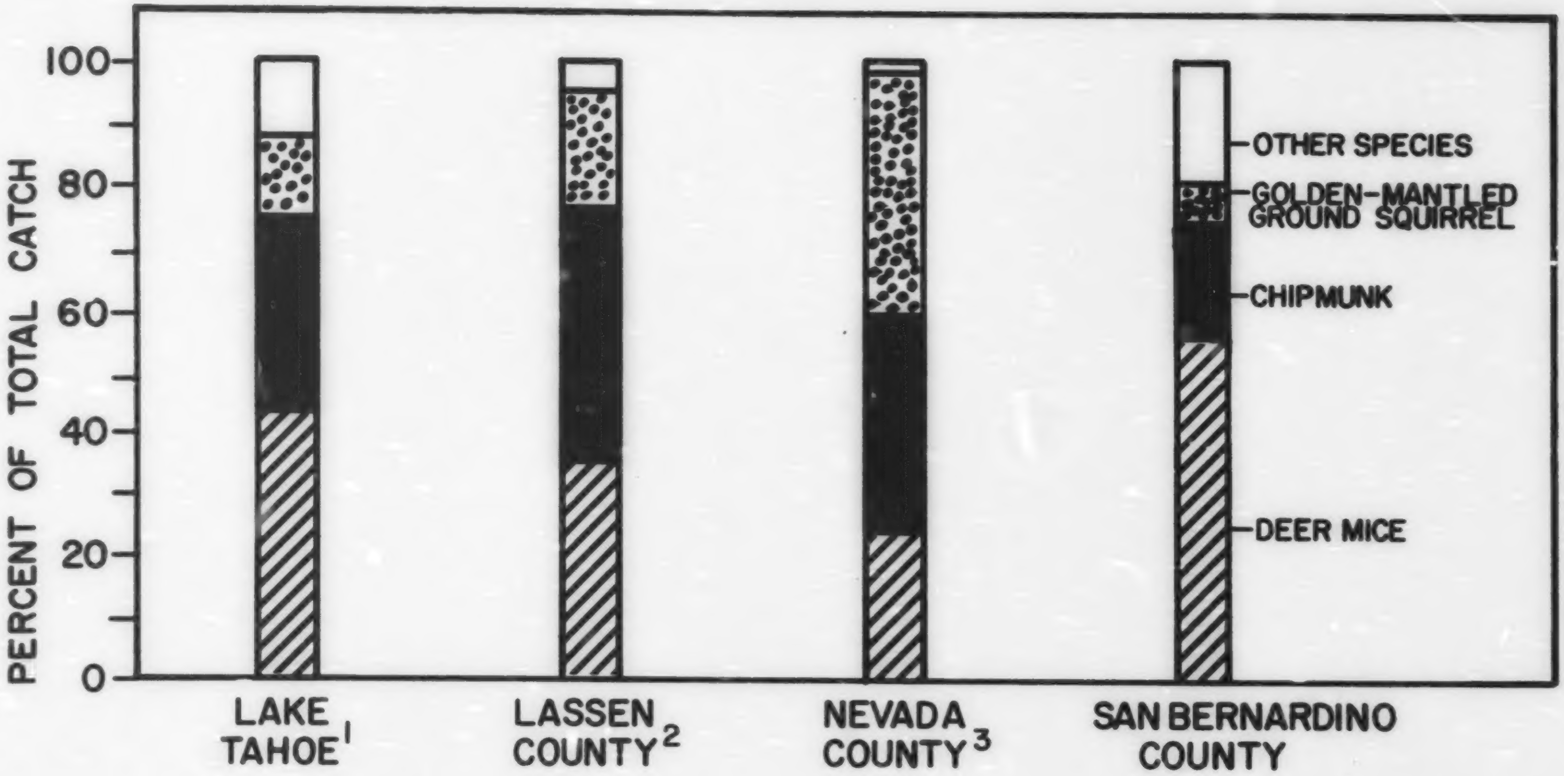


Figure 69. Number of small mammals caught per year per plot



-Figure 70. A comparison of the species composition of the small mammal catch on the study plot with the catch in three other forests in California.

literature. The small mammal catch on the study plots appears different from that on these three northern California forests as follows: (1) deer mice are more dominant; (2) chipmunks and golden-mantled ground squirrels comprise a smaller portion of the catch; and (3) the "other species" category is considerably larger. This latter difference is caused by the dusky-footed woodrats, which were the second most abundant species on the study plots, comprising 11.6% of the total catch. They do not occur on the three comparison areas.

Table 50 presents the percentage of trapping success on the study plots for 1972, 1973, and 1974. We use this percentage as an index of small mammal population density because of the difficulty of estimating densities directly from trapping results. The percentage of trapping success varied from a low of 2.3% in 1973 to a high of 7% in 1974. Major differences in the abundance of deer mice were the important cause of this marked change in trapping success. Even after allowing for different levels of trapping effort each year, there was a 6-fold increase in deer mice between 1972 levels and 1974 levels (Table 49).

TABLE 50. COMPARISON OF PERCENT TRAPPING SUCCESS OF SMALL MAMMALS IN 1972, 1973, 1974.

Year	Trap-days	Total catch	% trapping success
1972	2160	83	3.8
1973	3960	93	2.3
1974	4140	291	7.0
Totals	10260	467	4.5

The composite percentage of trapping success for the three years on the study plots was lower than that reported for the three northern California comparisons areas (Table 51). The reported percentages of trapping success ranged from 27.8% in Nevada County (Reichart and White ms) to 8.8 in Lassen County (McKeever, 1961). Table 51 also presents the marked differences in the percentage of trapping success found on the study plots according to smog injury ratings of the vegetation. The percentage of trapping success was markedly lower on plots with severe and moderate smog injury ratings.

Species diversity represents another way of describing a small mammal community. A total of 17 species was caught during this study, indicating that the small mammal fauna of this mixed conifer forest was well developed. On a plot-to-plot basis, the species diversity indices indicated that the small mammal fauna on plots where vegetation

TABLE 51. COMPARISON OF PERCENT TRAPPING SUCCESS OF SMALL MAMMALS ON FOUR FORESTS IN CALIFORNIA

Study area	Trap-days	Total catch	% trapping success
Reichart and White (ms) Nevada County	360	100	27.8
Storer et al. (1944) Lake Tahoe	1,658	195	11.8
McKeever (1961) Lassen County	1,920	170	8.8
White and Sweetwood (ms) San Bernardino County			
Smog injury rating of vegetation:			
Severe	1,035	15	1.4
Moderate	5,985	163	2.7
Very slight	720	64	8.9
No visible damage	2,520	225	8.9
Composite	10,260	467	4.5

TABLE 52. COMPARISON OF SPECIES DIVERSITY OF SMALL MAMMALS TRAPPED ON PLOTS WITH FOUR LEVELS OF VEGETATION INJURY FROM AIR POLLUTION.

Smog injury rating of vegetation	Number of plots	Number of species caught	Species diversity index*	
Severe	3	4	1.3	} .75
Moderate	9	9	1.0	
Very slight	2	5	2.5	}1.8
No visible symptoms	3	7	2.3	

*species diversity index = $\frac{\text{number of species caught}}{\text{number of plots}}$

exhibits severe and moderate smog injury ratings is only half as abundant as that on plots with very slight or no symptoms of smog injury to vegetation (Table 52).

Table 53 presents a preliminary analysis of the sex and age ratios of the small mammal catch. Species showing a possible surplus of males include the white-footed deer mouse, golden-mantled ground squirrel, and brush mouse. The dusky-footed woodrat and Beechey ground squirrel results suggest a surplus of females in the population. For the remaining species either the sex ratio appears approximately equal or the sample size was too small to make an accurate estimate.

From the initial 1972 period throughout the study, we have noted a larger and more diverse small mammal fauna on study plots with lower levels of photochemical air pollution. We hypothesize that the distribution and abundance of small mammals on the study areas probably correlates closely with the occurrence and quality of key vegetation and soil habitat requirements. Further, if these key habitat elements have been affected and/or are being affected by air pollution, then, in turn, air pollution will directly affect small mammal populations through this habitat alteration. A description of these effects and long-term trends is needed.

Western Gray Squirrel Observations--

Study of the western gray squirrel began in 1973 and continued through 1975. Abundant throughout the conifer forest, the gray squirrel depends on the yellow pine-black oak (Pinus ponderosa-Quercus kelloggii) vegetation mosaic for food, cover, and nest sites. The seed-squirrel relationship is very important in this forest system. An alteration of the balance between pine and oak through the agency of oxidant air pollution, or a change in the squirrel population directly due to oxidants, will affect the balance of the seed-squirrel relationship and have a significant influence on the forest, especially on pine and oak reproduction.

Preliminary census results on 43 live-trapped and ear-tagged squirrels (23 male : 20 female) on six study plots indicate a large, wide-spread population of gray squirrels, with small areas of unusual density. For example, on the Sky Forest plot, 18 individuals were tagged in 6 trap-days on an area of less than 0.2 hectares.

According to our measurements, yellow pine cone production increased in 1974 over 1973. The number of cones destroyed for seed eating by gray squirrels also was higher in 1974 than in 1973 (Fig. 71). Squirrels generally utilized the same trees in both years. Only four trees that were heavily utilized in 1973 were not used in 1974. All other trees heavily used in 1973 produced cones and were utilized in 1974. A good example of this "favored tree" syndrome was Jeffrey pine #1718 on the Schneider Creek plot: in 1973, 753 cones were cut; in 1974, 2,034 cones were cut.

In both years, the bulk of the cone utilization occurred on only a few of the 50 overstory yellow pine trees on each plot. The cones cut from tree #1718 represent 85% and 90%, respectively, of the total cone

TABLE 53. PRELIMINARY SEX AND AGE RATIOS OF THE TOTAL SMALL MAMMAL CATCH ON THE STUDY PLOTS, 1972-1974.*

	Sex ratios			Age ratios		
Species	Males	Females	Males/100 females	Adults	Immature	Immature/ 100 adults
White-footed deer mouse	162	132	123	127	163	78
Dusky-footed rat	36	49	73	55	29	190
Merriam chipmunk	29	26	112	20	35	57
Golden-mantled ground squirrel	22	17	129	30	9	333
Brush mouse	18	9	200	24	4	600
Botta pocket gopher	14	16	88	22	9	244
Lodgepole chipmunk	12	9	133	10	11	91
California meadow mouse	6	9	67	13	2	650
Beechy ground squirrel	13	19	68	17	15	113
Western harvest mouse	3	1	300	2	2	100
Pinyon mouse	9	5	180	5	9	56
California mouse	1	2	50	2	1	200
Western gray squirrel	9	10	90			
Northern flying squirrel	1	2	50	2	1	200
California pocket mouse						
Pacific kangaroo rat	2				2	
Ornate shrew						

*Includes some additional individuals obtained in other ways than snap-trapping

Note: Unidentified animals are not included - accounts for discrepancy.

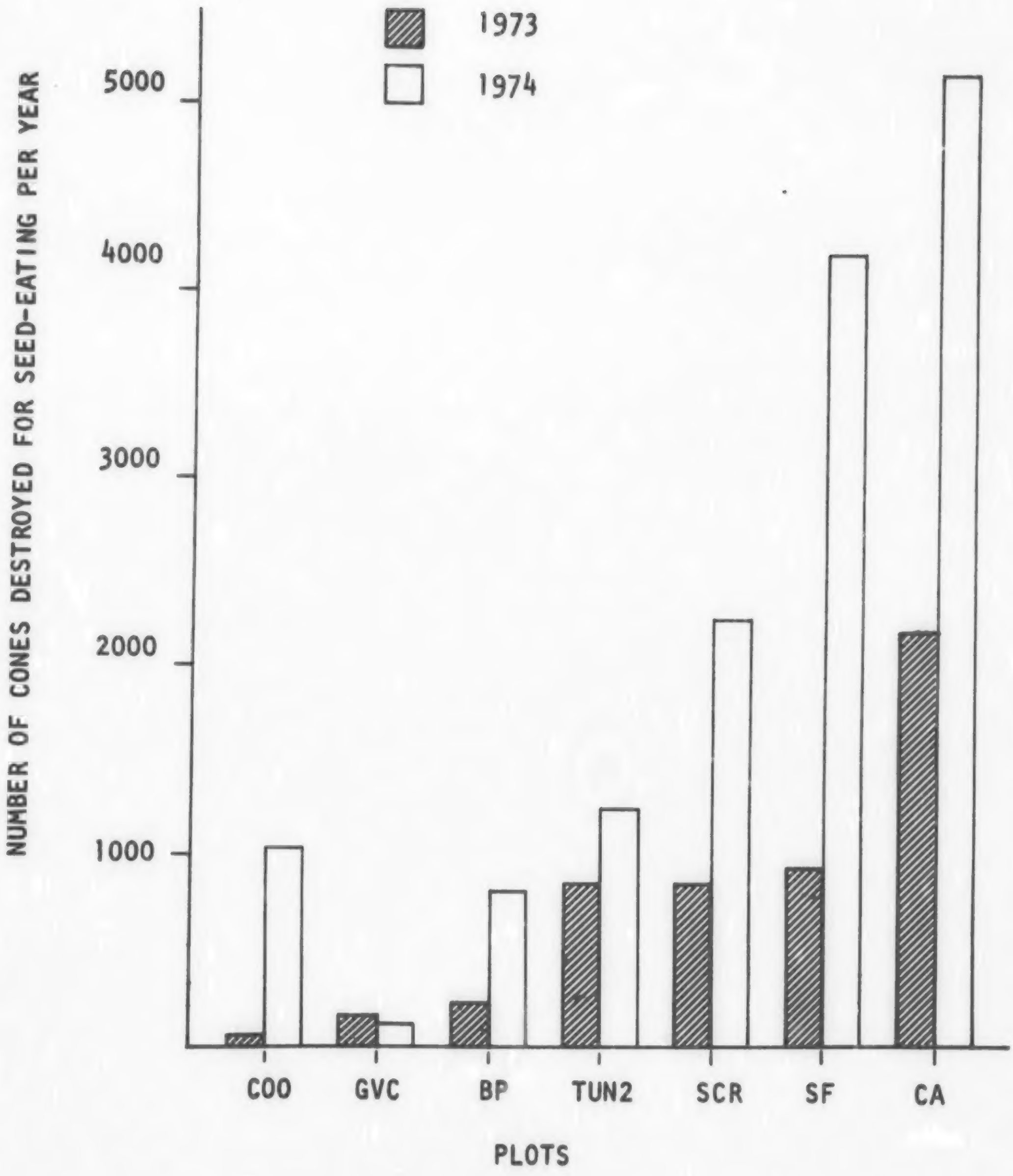


Figure 71. Comparison of cone utilization by gray squirrels in 1973 and 1974 by plot.

production for that plot in 1973 and 1974.

Gray squirrels began to cut green cones in June. In 1973, the first signs of cone-cutting appeared during the last week in June on the west side of the mountains. In 1974, workers on the west side noticed freshly cut cones by 10 June. Cone-cutting on the east side started somewhat later both years, but was underway by early July. Relatively few cones are cut during this early period through mid-July. From mid-June through mid-August the greatest amount of cone-cutting occurrs. In Figure 72, we separate the three plots with the greatest amount of cone utilization from the four lowest. The salient difference between the two groups was the sustained plane of high utilization on the three heavily utilized plots during this peak period. Cone-cutting dropped off in the weeks after mid-August. One Green Valley Creek and Schneider Creek, cone-cutting ceased in late August. On all other plots, cone-cutting continued at a low level in September and October.

A total of 14,844 cones were counted on the seven study plots in 1974; all of them were cut prior to seed maturity. This large loss of seed prior to maturity may be a factor acting in concert with oxidant air pollutant injury to depress the regeneration of yellow pine. In areas unaffected by oxidants, western gray squirrels are regarded as usually having limited or moderate effects on the overall regeneration potential of yellow pine (Moore 1940, Fowells and Schubert 1956, Larson and Schubert, 1970). However, cone cutting by squirrels in the oxidant-injury areas in the SBNF may be contributing to a hastening of vegetation change.

Future Activities--

Further trapping of small mammals and direct observations of the western gray squirrel are not planned at this time. The effects of these animals in the context of the stand succession modeling strategy will be monitored by the Cone and Seed Production and Seedling Establishement Subsystems.

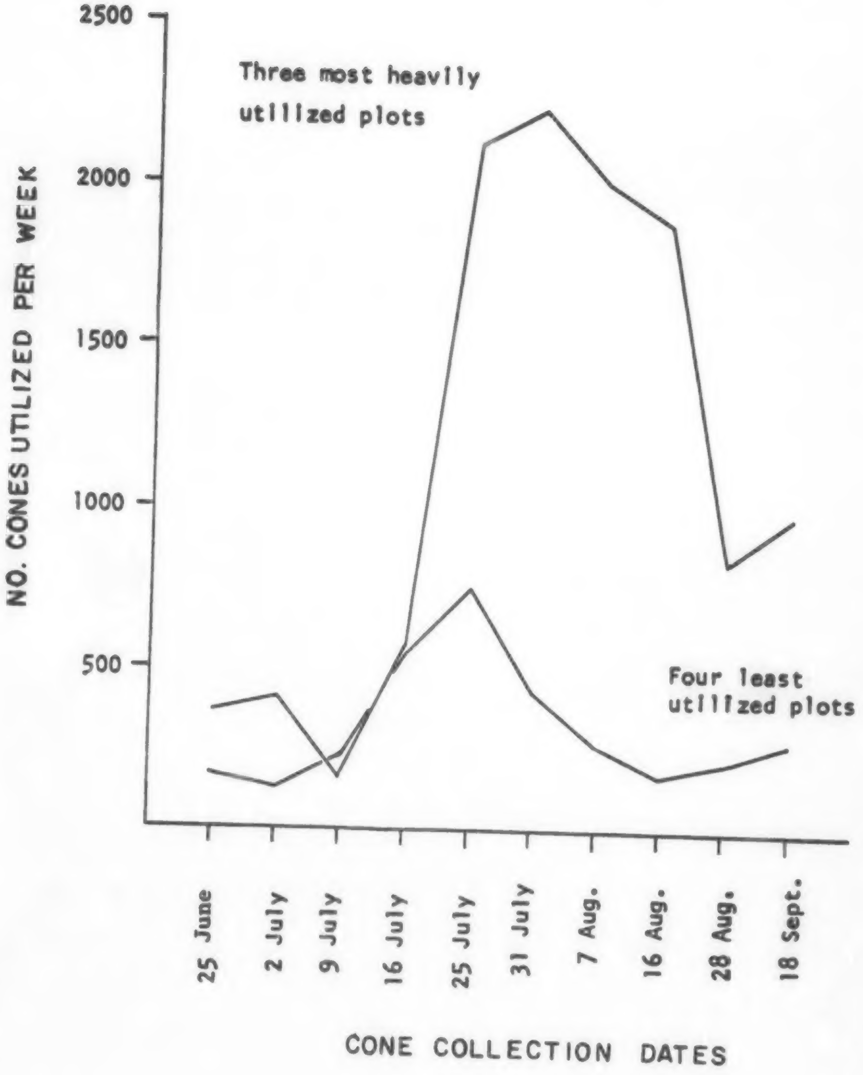


Figure 72. Extremes of weekly cone utilization by gray squirrels in 1974.

REFERENCES

Aldaz, L. 1969. Flux Measurement of Atmospheric Ozone Over Land and Water. In: Regener, V. H. and L. Aldaz. Studies of Atmospheric Ozone. Air Force Cambridge Research Laboratory. Contract No. AFCRL-69-0138, 12 pp.

Anonymous. 1976. Datamation 22(6):170.

American Society for Testing and Materials. 1973. Standard Method of Accelerated Laboratory Test of Natural Decay Resistance of Woods. In: Annual Book of ASTM Standards, Part 16, Designation: D-2017-71, Philadelphia, Pa. pp. 642-648.

Baker, F. S. 1948. A Short Method of Determining Leaf Area and Volume Growth in Pine Trees. Hilgardia 18(8):335-356.

Batschelet, E. 1971. Introduction to Mathematics for Life Scientists. Springer-Verlag, New York. 495 pp.

Baxter, D. V. 1952. Pathology in Forest Practice. John Wiley and Sons, Inc., New York, New York. 601 pp.

Bega, R. V., and R. S. Smith, Jr. 1966. Distribution of Fomes annosus in Natural Forests of California. Plant Dis. Reptr. 50:832-836.

Bennett, J. H., and A. C. Hill. 1975. Interactions of Air Pollutants With Canopies of Vegetation. In: Responses of Plants to Air Pollution. Mudd, J. B. and T. T. Kozlowski, eds., Academic Press, New York, New York. 383 pp.

Bennett, J. H., A. C. Hill and D. M. Gates. 1973. A Model for Gaseous Pollutant Sorption by Leaves. J. Air Pollut. Control Assoc. 23:957-962.

Biswas, A. K. 1975. Mathematical Modeling and Environmental Decision-making. Ecol. Modelling. 1(1):31-48.

Biswell, H. E. 1967. Forest Fire in Perspective. Ann. Tall Timbers Fire Ecol. Conf., Proc. 7:43-63.

Black, C. A. (ed.). 1965. Methods of Soil Analysis Agronomy No. 9, Part II. Madison, Wis., Amer. Soc. Agronomy, Inc. pp. 771-1572.

Black, H. C. (ed.). 1969. Wildlife and Reforestation in the Pacific Northwest. Sympos. Procs. Oregon State Univ., Corvallis. 92 pp.

Black, H. C. (ed.). 1974. Wildlife and Forest Management in the Pacific Northwest. Sympos. Procs. Oregon State Univ., Corvallis, 236 pp.

Blumenthal, D. L., W. H. White, R. L. Peace, and T. B. Smith. 1974. Determination of the Feasibility of Long Range Transport of Ozone or Ozone Precursors. U. S. Environmental Protection Agency, Research Triangle Park, N.C. Publication No. EPA-450/3-74-061. 92 pp.

Boe, K. N. 1954. Periodicity of Cone Crops for Five Montana Conifers. Mont. Acad. Sci., Proc. 14:5-9.

Boffey, P. M. 1976. International Biological Program: Was it Worth the Cost and Effort? Science. 193(4256):866-868.

Boling, R. H., Jr., and J. A. VanSickle. 1975. Control Theory in Ecosystem Management. In: Ecosystem Analysis and Prediction. Proc. SIAM-SIMS Conf., Alta, Utah, July 1-5, 1974, Levin, S. A. (ed.). Philadelphia, Society for Industrial and Applied Mathematics. pp. 219-229.

Bridges, K. W. 1974. Ecological Data Processing Facilities: A Brief Review and Proposal. University of Hawaii (Presented at National Park Service/Mississippi Test Facility, Bay St. Louis, Mississippi, May 23-24, 1974.) 5 pp.

Bryson, R. A., and W. M. Wendland. 1970. Climatic Effects of Atmospheric Pollution. In: Global Effects of Environmental Pollution, Singer, S. F. (ed.). D. Reidel, Dordrecht, Holland. pp. 130-138.

Burgess, A. 1967. The Decomposition of Organic Material in the Soil. In: Soil Biology. A. Burgess and F. Raw, eds. Academic Press, New York, N.Y., pp. 479-492.

Byler, J. W., D. R. Hart, and R. E. Wood. 1975. Forest Pest Evaluation System. U. S. Forest Service, Region V, San Francisco, CA (unpublished manuscript).

California Air Resources Board. 1976. Ambient Air Quality Standards. ARB Bulletin. March. p. 7.

California Air Resources Board. 1974. Report from the DeMore Committee.

Calhoun, J. B. 1959. Revised Sampling Procedures for the North American Census of Small Mammals (NACSM). U. S. Dept. HEW, Bethesda, Md. Population Dynamics of Vertebrates, Release No. 10. 12 pp.

Canfield, R. 1941. Application of the Line Interception Method in Sampling Range Vegetation. J. Forest. 39:388-394.

Charney, J., P. H. Stone, and W. J. Quirk. 1975. Drought in the Sahara: a Biogeophysical Feedback Mechanism. Science. 187:434-435.

Clarke, J. W. 1957. Comparative Decay Resistance of Some Common Pines, Hemlock, Spruce, and True Fir. Forest Science. 3:314-320.

Clements, F. E. 1905. Research Methods in Ecology. University Publishing Co., Lincoln, Nebraska. 361 pp.

Cobb, F. W., Jr., D. L. Wood, R. W. Stark, and J. R. Parmeter, Jr. 1968. Photochemical Oxidant Injury and Bark Beetle (Coleoptera: Scolytidae) Infestation of Ponderosa Pine. IV. Theory on the Relationship Between Oxidant Injury and Bark Beetle Infestation. Hilgardia. 39(6):141-152.

Corn, M., R. W. Dunlap, L. A. Goldmunc, and L. H. Rogers. 1975. Photochemical Oxidants: Sources, Sinks, and Strategies. J. Air Pollut. Contr. Assoc. 25:16-18.

Coyne, P. I. and G. E. Bingham. 197_. $C^{14}O_2$ Uptake and Needle Diffusional Resistance in Relation to Oxidant Damage in Ponderosa Pine. _In manuscript_.

Crossley, D. A., Jr., and K. K. Bohnsack. 1960. Long-term Ecological Study in the Oak-Ridge Area. 3. The Oribatid Mite Fauna in Pine Litter. Ecology. 4:628-38.

Curtis, J. T., and R. P. McIntosh. 1951. An Upland Forest Continuum in the Prairie-Forest Border Region of Wisconsin. Ecology. 32: 476-496.

Dahlsten, D. L. 1971. Parasites, Predators, and Associated Organisms Reared from Western Pine Beetle Infested Bark Samples. In: Studies on the Population Dynamics of the Western Pine Beetle, _Dendroctonus brevicomis_ LeConte (Coleoptera: Scolytidae), Stark, R. W. and D. L. Dahlsten (eds.). Berkeley, University of California Division of Agricultural Sciences. pp. 75-79.

Dahlsten, D. L. 1974a. The Role of Bark Beetles, _Dendroctonus_ spp. in the Succession of the Mixed Conifer Ecosystem, Exposed to Photochemical Air Pollutants. In: Protocol, Renewal EPA Contract 68-03-0273, Study of Effects of Oxidant Air Pollutants on a Mixed Conifer Forest Ecosystem. O. C. Taylor (ed.), Statewide Air Pollution Research Center, University of California, Riverside. pp. 45-59. (unpublished document).

Dahlsten, D. L. 1974b. The Role of Bark Beetles, _Dendroctonus_ spp., in the Succession of the Mixed Conifer Ecosystem Exposed to Photochemical Air Pollutants, Section III-C. In: Annual Progress Report 1973-74, for the U. S. Environmental Protection Agency, Corvallis, Or. 10 pp. and Appendix.

Dahlsten, D. L., C. J. DeMars, D. L. Rowney, and P. A. Felch. 1974. Sampling Techniques and Preliminary Analyses for the Western Pine Beetle in the Central Sierras of California. (Unpublished manuscript, in preparation).

Dahlsten, D. L., and D. L. Rowney. 1974. The Influence of Verticicladiella wagenerii on Western Pine Beetle, Dendroctonus brevicomis, Populations. (Unpublished progress report, Western Regional Project W-110). 5 pp.

Dahlsten, D. L. and F. M. Stephen. 1974. Natural Enemies and Insect Associates of the Mountain Pine Beetle, Dendroctonus ponderosae (Coleoptera: Scolytidae), in Sugar Pine. Canad. Entomol. 106:1211-1217.

Daubenmire, R. 1960. A Seven-Year Study of Cone Production as Related to Xylem Layers and Temperature in Pinus ponderosa. Amer. Midland Nat. 64:187-93.

Dickinson, C. H., and G. J. F. Pugh. 1974. Biology of Plant Litter Decomposition, Vols. I and II. Academic Press, New York. 776 pp.

Duff, G. H. and N. J. Nolan. 1954. Growth and Morphogenesis in Canadian Forest Species. Canada J. Botany. 31:471-513.

Edinger, J. G., M. H. McCutchan, P. R. Miller, B. C. Ryan, M. J. Schroeder, and J. V. Behar. 1972. Penetration and Duration of Oxidant Air Pollution in the South Coast Air Basin of California. J. Air Pollut. Contr. Assoc. 22:882-886.

Edmonds, R. L. and P. Sollins. 1974. The Impact of Forest Diseases on Energy and Nutrient Cycling and Succession in Coniferous Forest Ecosystems. Amer. Phytopath. Soc., Proc. 1:175-180.

Edwards, C. A., D. E. Reichle, and D. A. Crossley, Jr. 1970. The Role of Soil Invertebrates in the Turnover of Organic Matter and Nutrients. In: Analysis of Temperature Forest Ecosystems, Reichle, D. E. (ed.). Springer-Verlag, New York. pp. 147-172.

Eggins, H. O. W., and G. J. F. Pugh. 1962. Isolation of Cellulose-decomposing Fungi from the Soil. Nature. 193:94-94.

Environmental Protection Agency. 1970. The Clean Air Act. Washington, D.C. 56 pp.

Evans, L. S., and P. R. Miller. 1972. Ozone Damage to Ponderosa Pine: A Histological and Histochemical Appraisal. Am. J. Bot. 59:297-304.

Fowells, H. A., and G. H. Schubert. 1956. Seed Crops of Forest Trees in the Pine Region of California. U. S. Department of Agriculture, Washington, D.C. Tech. Bull. 1150. 48 pp.

Fries, J. 1974. Growth Models for Tree and Stand Simulation. Dept. Forest Yield Research, Royal College of Forestry, Stockholm, Sweden. Research Notes No. 30. 379 pp.

Fritts, H. C. 1974. Relationships of Ring Widths in Arid Site Conifers to Variations in Monthly Temperature and Precipitation. Ecol. Monogr. 44:411-440.

Fry, K. E., and R. B. Walker. 1967. A Pressure Infiltration Method for Estimating Stomatal Opening in Conifers. Ecology, 48:155-157.

Gashwiler, J. S. 1959. Small Mammal Study in West-Central Oregon. J. Mammal., 40(1):128-139.

Giese, R. L., R. M. Peart, and R. T. Huber. 1975. Pest Management. Science, 187(4181):1045-1052.

Giles, R. H., Jr. 1972. Future Uses of Computers in Environmental Management. In: Proc. Workshop on Computer and Information Systems in Resources Management Decisions, Sept. 30, 1971. Stone, R. N., and K. D. Ware (eds.). Washington, D.C.: U. S. Forest Service. pp. 3-21.

Glendening, G. 1952. Some Quantitative Data on the Increase of Mesquite and Cactus on a Desert Grassland Range in Southern Arizona. Ecology. 33:319-328.

Gloria, H. R., G. Bradburn, R. F. Reinisch, J. N. Pitts, Jr., J. V. Behar, and L. Zafonte. 1974. Airborne Survey of Major Air Basins in California. J. Air. Pollut. Contr. Assoc. 24:645-652.

Goodall, D. W. 1972. Integration of Shrub Research Effort. In: Wildland Shrubs - Their Biology and Utilization. USDA Forest Serv. Intermt. For. and Range Exp. Stn., Ogden, Utah. Gen. Tech. Rep. INT-1. pp. 435-439.

Graham, S. A., and F. B. Knight. 1965. Principles of Forest Entomology. 4th Edition. McGraw-Hill Book Co., New York, N.Y. 417 pp.

Grier, C. C. and R. H. Waring. 1974. Conifer Foliage Mass Related to Sapwood Area. Forest Science 20:205-206.

Habeck, J. R., and R. W. Mutch. 1973. Fire-dependent Forests in the Northern Rocky Mountains. Quarternary Research. 3(3):408-424.

Hagar, D. C. 1960. The Interrelationships of Logging, Birds, and Timber Regeneration in the Douglas-Fir Region of Northwestern California. Ecology. 4(1):116-125.

Hampel, V. and J. Ramus. 1975. Master Control - a Users' Manual. Lawrence Livermore Laboratory, Livermore, California. (Unpublished report). p. 181.

Hanes, T. L. 1971. Succession After Fire in the Chaparrel of Southern California. Ecol. Mono., 41:27-52.

Holling, C. S. 1974. Resilience and Stability of Ecological Systems. Ann. Rev. Ecol. System. 4:1-24.

Holling, C. S. and A. D. Chambers. 1973. Resource Science: the Nurture of an Infant. Bioscience. 23(1):13-20.

Hooven, E. F. 1969. The Influence of Forest Succession on Populations of Small Animals in Western Oregon. In: Proc., Wildl. and Reforest. in the Pacific Northwest Sympos. Sept. 12-13, 1968. Black, H. C. (ed.) School of Forestry, Oregon State University, Corvallis, Oregon. pp. 30-34.

Hornibrook, E. M. 1939. A Modified True Classification for Use in Growth Studies and Timber Marking in Black Hills Ponderosa Pine. J. Forest. 37:483-88.

Horton, J. S. 1960. Vegetation Types of the San Bernardino Mountains. U. S. Forest Serv., Pacific Southwest Forest and Range Expt. Sta., Berkeley, CA. Tech. Paper No. 44. 29 pp.

Innis, G. 1973. Simulation of Ill-defined Systems: Some Problems and Progress. Simulation Today. 9:33-36.

Jackson, M. L. 1960. Soil Chemical Analysis. Prentice-Hall, Inc., Englewood, Cliffs, N.J. 498 pp.

Jeffers, J. N. R. 1973. Systems Modeling and Analysis in Resource Management. J. Environ. Mgmt. 1:13-28.

Johnson, C. M., and Ulrich, A. 1959. II. Analytical Methods for Use in Plant Analysis. Calif. Agr. Expt. Sta. Bull. 766. 77 pp.

Keen, F. P. 1936. Relative Susceptibility of Ponderosa Pines to Bark Beetle Attack. J. Forest. 34:919-927.

Kickert, R. N., P. R. Miller, O. C. Taylor, J. R. McBride, J. Barbieri, R. Arkley, F. Cobb, Jr., D. Dahlsten, W. W. Wilcox, J. Wenz, R. J. Parmeter, Jr., R. F. Luck, and M. White. 1976. Photochemical Air Pollutant Effects on Mixed Conifer Forest Ecosystems - A Progress Report. In press. (USEPA)

Kilgore, B. M. 1973. The Ecological Role of Fire in Sierran Conifer Forests. Quat. Res. 3(3):496-513.

Kittredge, J. 1944. Estimation of the Amount of Foliage of Trees and Stands. J. Forestry. 42:905-912.

Knapp, R. 1974. Handbook of Vegetation Science. W. Junk Publishers, The Hague, The Netherlands. 368 pp.

Koenig, H. E., and R. L. Tummala. 1972. Principles of Ecosystem Design and Management. IEEE Transactions on Systems, Man, and Cybernetics.

SMC-2(4):449-459.

Kolb, J. A., and M. White. 1974. Small Mammals of the San Bernardino Mountains, California. The Southwestern Naturalist 19(1):112-114.

Kramer, P. J., and K. K. Kozlowski. 1960. Physiology of Trees. McGraw-Hill, Publishing Co., New York. 642 pp.

Kupperman, R. H., R. H. Wilcox, and H. A. Smith. 1975. Crisis Management: Some Opportunities. Science. 187(4175):404-410.

LaChapelle, E. R. 1967. Timberline Reforestation in the Austrian Alps. J. For. 65(12)868-872.

Larsen. 1973. An Air Quality Data Analysis System for Interrelating Effects, Standards, and Needed Source Reductions. J. Air Poll. Contr. Assoc. 23:933-940.

Larson, N. M., and G. H. Schubert. 1970. Cone Crops of Ponderosa Pine in Central Arizona, Including the Influence of Abert Squirrels. U. S. Forest Service. Rocky Mt. For. & Range Exp. Sta., Fort Collins, Colo. Research Paper. RM-58 15 pp.

Lawrence, W. H. 1958. Wildlife-damaged Control Problems on Pacific Northwest Tree Farms. North Amer. Wildl. Conf. Trans. 23:146-152.

Leak, W. B. 1970. Successional Change in Northern Hardwoods Predicted by Birth and Death Simulation. Ecology. 51:794-801.

Levin, S. 1975. Ecosystem Level Concepts. In: Ecosystem Analysis and Prediction. Proc. SIAM-SIMS Conference, Alta, Utah, July 1-5, 1974, Levin, S. A. (ed.). Philadelphia, Society for Industrial and Applied Mathematics. pp. 129-130.

Levins, R. 1966. Strategy of Model Building in Population Biology. Amer. Sci. 54:421-431.

Lowry, W. P. 1966. Apparent Meteorological Requirements for Abundant Cone Crops in Douglas-fir. Forest Sci. 12:185-192.

Maguire, W. P. 1956. Are Ponderosa Pine Cone Crops Predictable? J. Forest. 54:778-9.

Mar, B. W. 1974. Problems Encountered in Multicisciplinary Resources and Environmental Simulation Models Development. J. Environ. Manag. 2:83-100.

McBride, J. 1973. Vegetation of Principle Study Sites in the San Bernardino Mountains. In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task C Report. Statewide Air Pollution Research Center, Univ. of Calif., Riverside, Calif. pp.

McBride, J. 1974. Plant Succession in the Berkeley Hills, California. Madrono. 22:317-329.

McBride, J. R. 1974. Annual Report of the Vegetation Subcommittee for the Fiscal Year Ending June 15, 1974, Section III-B. In: Annual Progress Report 1973-74, for the U. S. Environmental Protection Agency, Corvallis, Ore. 22 pp.

McBride, J. R., F. Cobb, and D. Dahlsten. 1976. Proportional Causes and Rates of Tree Mortality. In: Renewal Proposal to the Environmental Protection Agency for 1976-1977, Photochemical Air Pollution Effects on Mixed Conifer Forest Ecosystems, O. C. Taylor, ed., Statewide Air Pollution Research Center, University of California, Riverside. pp. E2-E6.

McBride, J. et al. 1975. A Checklist of the Vascular Plants of the Montane Coniferous Forest in the San Bernardino Mountains, Calif. Department of Forestry & Conservation. University of California, Berkeley, California. 45 pp.

McBride, J. et al. 1976. Vascular Plants of Montane Coniferous Forests in San Bernardino Mountains, Calif. Madrono 23:299.

McBride, J., and R. Laven. 1976. Scars as Indicators of Fire Frequency in the San Bernardino Mountains, California. J. Forestry. 75: 334-338.

McBride, J., and E. C. Stone. 1976. Plant Succession on the Sand Dunes of Monterey Peninsula, California. Amer. Midl. Naturalist, 96:118-132.

McCutchan, M. H. 1974. Forest Fire Meteorology Research Network. In: Automated Meteorological Systems, World Meteorological Organ. #420. pp. 352-59.

McCutchan, M. H., and M. J. Schroeder. 1973. Classification of Meteorological Patterns in Southern California by Discriminant Analysis. J. Appl. Meteorol. 12:571-577.

McKeever, S. 1961. Relative Populations of Small Mammals in Three Forest Types of Northeastern California. Ecology, 42(2):399-402.

Meyer, H. A., and D. D. Stevenson. 1943. The Structure and Growth of Virgin Beech-Birch-Maple-Hemlock Forests in Northern Pennsylvania. J. Agr. Res., 67:465-484.

Millar, C. S. 1974. Decomposition of Coniferous Leaf Litter. In: Biology of Plant Litter Decomposition. Dickinson, C. M., and G. J. F. Pugh (eds.). Academic Press, New York. pp. 105-128.

Miller, J. M., and F. P. Keen. 1960. Biology and Control of the Western Pine Beetle. A Summary of the First Fifty Years of Research. U.

S. Department of Agriculture Forest Service, Washington, D.C. Misc. Publ. No. 800, 381 p.

Miller, W. J. 1946. Crystalline Rocks of Southern California. Geol. Soc. Amer. Bull. 57:457-542.

Miller, P. R. 1973a. Oxidant-induced Community Change in a Mixed Conifer Forest. In: Air Pollution Damage to Vegetation, Nagele, J. A. (ed.). Advances in Chem. Ser. 122:101-117.

Miller, P. R. 1973b. Oxidant Damage to Conifers on Selected Study Sites, 1972. In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task C. Report: Study Sites Selection and Verification Data on Pollutants and Species. Taylor, O. C. (ed.). U. S. Environmental Protection Agency, Corvallis, Ore. Section III. 20 p.

Miller, P. R. 1973c. Oxidant Damage to Conifers on Selected Study Sites. In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task C. Report: Study Site Selection and Verification Data on Pollutants and Species, O. C. Taylor, ed. U. S. Environmental Protection Agency, Corvallis, Ore., Section III. 20 pp.

Miller, P. R. 1974. Environmental Monitoring and Measurement of Oxidant Damage to Vegetation in the San Bernardino Mountains, Section A. In: Annual Progress Report 1973-1974, for the U. S. Environmental Protection Agency, Corvallis, Ore. 12 pp.

Miller (unpublished data)

Miller, P. R., J. R. Parmeter, Jr., B. H. Flick, and C. W. Martinez. 1969. Ozone Damage Response of Ponderosa Pine Seedlings. J. Air Pollut. Contr. Assoc. 19:435-438.

Miller, J. M., and F. P. Keen. 1960. Biology and Control of the Western Pine Beetle. A Summary of the First Fifty Years of Research. U. S. Department of Agriculture Forest Service, Washington, D.C. Misc. Publ. No. 800. 381 pp.

Miller, P. R., and J. R. McBride. Vegetation Committee Report (Sec. A) In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task B Report. Statewide Air Pollution Research Center, Univ. of Calif., Riverside, CA.

Miller, P. R. and A. A. Millecan. 1971. Extent of Oxidant Air Pollution Damage to Some Pines and Other Conifers in California. Plant Dis. Reptr. 55:555-559.

Miller, W. J. 1946. Crystalline Rocks of Southern California. Geol. Soc. Amer. Bull., 57:457-542.

Minnich, R. C., L. W. Bowden, and R. W. Pease. 1969. Mapping Montane Vegetation in Southern California. -- Status Report 3, Contract No. 14-08-0001-10674. U. S. Department of the Interior, Tech. Report 3. Dept. of Geography, Univ. Calif., Riverside, Ca. 40 pp.

Mitchell, R., R. A. Meyer and J. Downhower. 1976. An Evaluation of Three Biome Programs. Science. 192:859-865.

Moore, A. W. 1940. Wild Animal Damage to Seed and Seedlings on Cut-over Douglas-fir Lands of Oregon and Washington. U. S. Department of Agriculture, Washington, D.C. Tech. Bull. No. 706. 28 pp.

Mukammal, E. I. 1965. Ozone as a Cause of Tobacco Injury. Agr. Meteorol. 2:145-165.

Munn, R. E. 1970. Biometeorological Methods. Academic Press, New York. 336 pp.

National Academy of Sciences, 1974. U. S. Participation in the International Biological Program. U. S. National Committee for the International Biological Program, Washington, D.C. Report No. 6. 165 pp.

National Science Board. 1972. Terrestrial Ecosystems. In: Patterns and Perspectives in Environmental Science. National Science Foundation, Washington, D.C. pp 277-315.

Noy-Meir, I. 1973. Desert Ecosystems: Environment and Producers. Ann. Rev. Ecol. System. 4:25-51.

Odum, E. P. 1971. Fundamentals of Ecology. W. B. Saunders Co., Philadelphia. 574 pp.

Ott, Wayne R. (ed.). 1976. Proc. of the Conf. on Environmental Modeling and Simulation. April 19-22, 1976, Cincinnati, Ohio. EPA 600/9-76-016. Office of Research and Development, and Office of Planning and Management, U. S. Environmental Protection Agency. 847 pp.

Patton, D. R. 1975. Abert Squirrel Cover Requirements in Southwestern Ponderosa Pine. USDA For. Serv. Res. Pap. RM-145. 12 p.

Pitts, J. N., Jr., J. L. Sprung, M. Poe, M. C. Carpelan and A. C. Lloyd. 1976. Corrected South Coast Air Basin Oxidant Data: Some Conclusions and Implications. Environ. Sci. and Tech. 10:794-801.

Pearson, G. A. 1923. Natural Reproduction of Western Yellow Pine in the Southwest. U. S. Department of Agriculture, Washington, D.C., Bull. 1105. 143 pp.

Price, D. W. 1973. Abundance and Vertical Distributions of Microarthropods in the Surface Layers of a California Pine Forest Soil. Hilgardia. 42(4):121-148.

Puritch, G. S. 1972. Cone Production in Conifers. Pacific Forest Research Centre, Canadian Forest Serv., Dept. Environment, Victoria, British Columbia. Information Report (BC-X-65). 94 pp.

Reed, K. L. 1976. Prediction of Tree Growth Response Surfaces in an N-Dimensional Habitat Coordinate System. (in Preparation)

Reed, K. L., and S. G. Clark. 1976. Succession Simulator: A Coniferous Forest Simulator. Model Documentation. Coniferous Forest Biome Bulletin No. 11, University of Washington, Seattle, Wash. (in preparation).

Reed, K., and R. H. Waring. 1974. Coupling of Environment to Plant Responses: a Simulation Model of Transpiration. Ecology. 55(1): 62-72.

Reichart, H. A., and M. White. no date. Small Mammal Population in Six Habitats, Sagehen Creek, California. Ms., 30 pp.

Riddell, R. W. 1950. Permanent Stained Mycological Preparations Obtained by Slide Culture. Mycologia. 42:265-270.

Roeser, J., Jr. 1941. Some Aspects of Flower and Cone Production in Ponderosa Pine. J. Forest. 39:534-536.

Ryan, B. C. 1974. A Mathematical Model for Diagnosis and Prediction of Surface Winds in Mountainous Terrain. Ph.D. Dissertation, Department of Geography, University of California, Riverside. 135 pp.

Sabersky, R. H., D. A. Sinema, and F. H. Shair. 1973. Concentrations, Decay Rates and Removal of Ozone and Their Relation to Establishing Clean Indoor Air. Environ. Sci. Technol. 7:347-353.

Scholander, P. F., H. T. Hammel, D. Broadstreet and E. Z. Hemmingsen. 1965. Sap Pressure in Vascular Plants. Science. 148:339-346.

Slavik, B. 1974. Methods of Studying Plant Water Relations. Springer-Verlag, New York, New York. 449 pp.

Smith, W. H. 1970. Tree Pathology: A short introduction. Academic Press, New York, New York. 309 pp.

Smith, W. H. 1974. Air Pollution-Effects on the Structure and Function of the Temperate Forest Ecosystem. Environ. Pollut. 6:111-129.

Smith, C. F., and S. E. Aldous. 1947. The Influence of Mammals and Birds in Retarding Artificial and Natural Reseeding of Coniferous Forests in the United States. J. Forestry. 45:361-369.

Soil Survey Staff, Soil Taxonomy. U. S. Department of Agriculture Soil Conservation Service. (In preparation.)

Sollins, P., R. H. Waring, and D. W. Cole. 1974. A Systematic Framework for Modeling and Studying the Physiology of a Coniferous Forest Ecosystem. In: Integrated Research in the Coniferous Forest Biome. Bulletin No. 5. Waring, R. H. and R. L. Edmonds (eds.). University of Washington, Seattle, Wash. pp. 7-20.

Stage, A. R. 1973. Prognosis Model for Stand Development. USDA For. Serv. Intermountain Forest and Range Expt. Sta., Ogden, Utah. Res. Pap. INT-137. 32 pp.

Stark, N. 1973. Nutrient Cycling Pathways and Litter Fungi. Bioscience, 22:335-360.

Stark, N. 1973. Nutrient Cycling in a Jeffrey Pine Ecosystem. Montana Forest and Conservation Experiment Station. 389 pp.

Stark, R. W., and D. L. Dahlsten (eds.). 1970. Studies on the Population Dynamics of the Western Pine Beetle, Dendroctonus brevicomis Le Conte (Coleoptera: Scolytidae). Univ. of Calif., Div. Agr. Sci., Berkeley, Ca. 174 pp.

Stark, R. W., P. R. Miller, F. W. Cobb, Jr., D. L. Wood, and J. R. Parmeter. 1968. Photochemical Oxidant Injury and Bark Beetle (Coleoptera: Scolytidae) Infestation of Ponderosa Pine. I. Incidence of Bark Beetle Infestation in Injured Trees. Hilgardia, 39(6):121-126.

Storer, T. I., F. C. Evans, and F. G. Palmer. 1944. Some Rodent Populations in the Sierra Nevada of California. Ecol. Monogrs. 14(2): 166-192.

Taylor, O. C., (ed.). 1974. Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Annual Progress Report 1973-74. U. S. Environmental Protection Agency, Corvallis, Ore. 116 pp.

Thompson, W. G. 1940. A Growth Rate Classification of Southwestern Ponderosa Pine. J. Forest. 38:547-53.

Tiao, G. C., M. S. Phadke, and G. E. P. Box. 1976. Some Epirical Models of the Los Angeles Photochemical Smog Data. J. Air Pollut. Contr. Assoc. 26:485-490.

U. S. Forest Service. 1973. Timber Inventory Map, U. S. Department of Agriculture, San Bernardino National Forest, San Bernardino, Ca.

Van Dyne, G. M. 1972. Organization and Management of an Integrated Ecological Research Program. In: Mathematical Models in Ecology, Jeffers, J. N. R. (ed.). Blackwell Scientific Publications, London. 398 pp.

Vohs, P. A. 1974. Forest and Wildlife Management: Conflict and Coordination. In: Wildlife and Forest Management in the Pacific Northwest, H. C. Black, (ed.) Sympos. Proc. Oregon State Univ., Corvallis, Ore. pp. 21-26.

Weaver, H. 1964. Fire and Management Problems in Ponderosa Pine. Ann. Tall Timber Fire Ecol. Conf., Proc. 3:61-79.

Wellner, C. A. 1970. Fire History in the Northern Rocky Mountains. Symp. Role of Fire in the Intermountain West, Proc. Intermountain Res. Council, Missoula, Mont. 42-64.

White, M., and J. A. Kolb. 1973. A Survey of Terrestrial Vertebrates in the Mixed Conifer Portion of the San Bernardino Mountains. In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task C: Study Site Selection and Verification Data on Pollutants and Species. Taylor, O. C. (ed.). U. S. Environmental Protection Agency. Corvallis, Ore. Section VII. 54 pp.

White & Sweetwood (In manuscript)

Wiegert, R. G. 1975. Simulation Model of Ecosystems. Ann. Rev. Ecol. System. 6:311-338.

Wood, D. L. 1971. The Impact of Photochemical Air Pollution on the Mixed Conifer Forest Ecosystem Arthropods. In: Oxidant Air Pollutant Effects on a Western Coniferous Forest Ecosystem. Task B Report: Historical Background and Proposed Systems Study of the San Bernardino Mountain Area. U. S. Environmental Protection Agency, Corvallis, Ore., Section C. 26 pp.

Woodwell, G. M. 1970. Effects of Pollution on the Structure and Physiology of Ecosystems. Science. 168:429-433.

Woodwell, G. M. 1975. The Threshold Problem in Ecosystems. In: Ecosystem Analysis and Prediction. Proc. SIAM-SIMS Conference, Alta, Utah, July 1-5, 1974. Levin, S. A. (ed.). Philadelphia, Society for Industrial and Applied Mathematics. pp. 9-21.

Yorke, (See Boling and Van Sickle, 1975)

Zeldin, 1975. Meteorological Aspects of Ozone Prediction. California Air Environ. 6(1):6.

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Appendix A. CLASSIFICATION OF SOILS OF MAJOR PLOTS IN THE SAN BERNARDINO MOUNTAINS.

Plot	Soil Series	Classification: Soil Taxonomy (1973)
Lake Arrowhead Region		
Dogwood	Shaver	Pachic Ultic Haploxeroll, coarse loamy, mixed, mesic
	Unnamed-1	See below
Sky Forest	Shaver	See above
	Unnamed-1	Pachic Ultic Argixeroll, fine loamy, mixed, mesic
NE13	Shaver	See above
S22	Crouch	Ultic Haploxeroll, coarse loamy, mixed, mesic
UC Conf. Cen.	Unnamed-2	Ultic Argixeroll, fine loamy, mixed, mesic
NW Camp Paivika	Shaver	See above
Breezy Point	Shaver	See above
Tunnel Two	Stump Springs	Ultic Haploxeralf, fine loamy, mixed, mesic
East of Lake Arrowhead Region		
Camp O-Ongo		
25M, 13 M R.		
76M, 7 M R.	Unnamed-3	Typic Xerorthent, coarse loamy, mixed, frigid
58M, 11 M L.	Unnamed-4	Entic Xerumbrept, coarse loamy, mixed, frigid
142M, 2 M R.	Unnamed-5	Pachic Xerumbrept, coarse loamy, mixed, frigid

Appendix A. CLASSIFICATION OF SOILS OF MAJOR PLOTS IN THE SAN BERNARDINO MOUNTAINS. (Continued)

Plot	Soil Series	Classification: Soil Taxonomy (1973)
Green Valley Creek		
(Valley)	Unnamed-6	Entic Xerumbrept, sandy, mixed, mesic
(Hill)	Unnamed-7	Typic Xerorthent, sandy, mixed, mesic
Snow Valley 0-156M	Heitz	Lithic Xeropsamment, mixed, frigid
156-249M	Chiquito	Entic Xerumbrepts, coarse loamy, mixed, frigid
NE GREEN VALLEY		
0- 60M	Corbett	Typic Xeropsamment, mixed, frigid
60-175M	Heitz	Lithic Xeropsamment, mixed, frigid
Big Bear Lake Region		
Bluff Lake	Gefo Variant	Typic Xerombrupt, sandy, mixed, frigid
	Ducey Variant	Typic Xerumbrept, coarse loamy, mixed, frigid
Holcomb Valley	Domingo	Typic Argixeroll, fine loamy, mixed, mesic
	Unnamed-10	Typic Haploxeroll, coarse loamy, mixed, mesic

Appendix A. CLASSIFICATION OF SOILS OF MAJOR PLOTS IN THE SAN BERNARDINO MOUNTAINS. (Continued)

Plot	Soil Series	Classification: Soil Taxonomy (1973)
Sand Canyon		
(Granite area)		
	Heitz	Lithic Xeropsamment, mixed, frigid
	Unnamed-8	Lithic Xerorthent, coarse loamy, mixed, acid, frigid
	Delleker Variant	Typic Haploxeralf, fine loamy, mixed, frigid
	Unnamed-3	Typic Xerorthent, coarse loamy, mixed, frigid
(Mixed alluvial area)		
	Unnamed-9	See above
	Gefo Variant	Typic Xerumbrepts, sandy, mixed, frigid
Santa Ana Canyon Region		
Camp Angelus	Cahto Variant	Pachic Ultic Haplixeroll, loamy-skeletal, mixed, mesic
	Unnamed-10	Typic Haploxeroll, coarse loamy, mixed, mesic
Schneider Creek	Crouch Variant	Ultic Haploxeroll, sandy, mixed, mesic
Heart Bar	Gearson Variant	Typic Haploxeroll, sandy, mixed, frigid
	Unnamed-11	Typic Xerochrept, sandy, mixed, frigid

Appendix B. PARTICLE SIZE DISTRIBUTION AND pH OF REPRESENTATIVE SOIL SAMPLES FROM MAJOR STUDY PLOTS.

Plot-site	Depths (cm)	Sand 2-.05 mm (%)	Silt .05-.002 mm (%)	Clay <.002 mm (%)	Fine Gravel 2-12mm (%)	Gravel >12mm (%)	pH
Dogwood-1	0-23	71.6	20.3	8.1	29.0	1.3	5.83
	77-99	62.7	19.1	18.1	62.3	0.6	5.73
	122-141	69.2	19.6	11.2	38.3	0.4	5.59
Dogwood-2	0-19	72.8	20.7	6.6	21.7	0.0	6.05
	112-126	67.7	16.9	15.4	51.6	2.7	5.53
	173-198	74.6	20.5	4.8	28.0	0.3	5.52
Dogwood-3	0-25	69.2	18.2	12.6	42.2	0.9	5.40
	29-112	71.4	16.7	12.0	42.8	1.3	5.70
	119-140	69.1	14.2	16.7	42.3	0.6	5.50
S 22	0-20	74.0	18.1	7.9	0.2	4.9	6.75
	41-58	74.2	18.1	7.6	7.0	5.0	5.80
	79-99	77.5	14.8	7.7	6.9	0.6	5.33
NE 13	0-24	74.7	15.8	9.5	29.2	7.7	6.28
	109-133	74.2	13.8	12.0	36.8	0.0	5.50
	246-272	78.3	15.6	6.1	37.1	0.4	5.21
UC Conf. Cen.	0-25	69.1	24.9	6.1	24.7	1.9	5.91
	71-99	58.3	21.6	20.1	41.0	0.0	5.58
	250-268	73.8	19.7	6.5	34.2	0.0	4.88
Sky Forest R.S.	0-15	71.2	18.5	10.3	0.0	2.2	5.53
	91-107	71.9	20.7	7.4	6.4	2.0	5.80
	208-231	76.2	18.1	5.7	5.2	0.3	5.50
Breezy Point	0-29	69.9	20.6	9.5	20.6	0.8	5.92
	102-127	73.0	19.2	7.8	25.5	0.0	5.68
	208-231	82.2	12.6	5.1	27.9	0.0	5.65
Camp O-Ongo	0-24	67.0	24.8	8.2	30.0	0.5	5.94
	72-93	65.0	22.2	12.9	50.0	4.4	5.63
	110-128	55.5	28.4	16.1	55.2	0.5	5.35
	128-149	56.9	35.0	8.2	93.4	0.0	5.36

Appendix B. PARTICLE SIZE DISTRIBUTION AND pH OF REPRESENTATIVE SOIL SAMPLES FROM MAJOR STUDY PLOTS. (Continued)

Plot-site	Depths (cm)	Sand 2-.05 mm (%)	Silt .05-.002 mm (%)	Clay <.002 mm (%)	Fine Gravel 2-12mm (%)	Gravel >12mm (%)	pH
Green	0-29	76.6	16.1	7.3	48.8	1.9	6.05
Valley	98-121	78.7	17.2	4.1	52.8	0.6	5.78
Creek	212-234	84.2	13.0	2.8	28.6	0.1	5.21
NE Green	0-22	82.4	11.5	6.1	37.6	0.8	6.00
Valley	81-104	84.7	12.6	2.8	31.4	0.0	6.13
Snow	0-14	75.3	16.1	8.6	28.1	0.0	5.40
Valley	33-46	74.4	16.1	9.5	40.0	0.0	5.00
Bluff Lake	0-28	79.4	14.0	6.6	34.8	0.2	5.74
	103-127	78.2	15.2	6.6	44.4	0.7	5.79
	189-211	82.2	11.2	6.6	47.0	0.0	5.89
Holcomb	0-13	69.4	18.8	11.8	30.0	3.7	6.18
Valley	28-43	67.3	16.2	16.5	71.0	0.3	6.43
	94-110	70.7	14.8	14.5	83.1	2.3	7.70
Sand	0-25	79.9	12.6	7.5	39.6	0.1	6.52
Canyon	87-110	82.0	14.9	3.2	34.1	0.0	6.08
Schneider	0-14	79.8	14.1	6.1	104.2	0.9	6.51
Creek	81-104	81.7	12.9	5.3	63.1	0.1	6.45
	166-189	81.4	13.1	5.6	58.2	0.0	6.46
Barton	0-15	71.2	19.4	9.4	4.2	ND	6.15
Flat	61-76	69.5	22.4	8.1	7.4	ND	6.45
Heart Bar	0-15	84.8	9.9	5.3	5.2	ND	6.81
	91-107	81.8	8.1	10.1	7.3	ND	6.11
	122-137	81.4	8.9	9.1	5.6	ND	6.13
Camp	0-15	17.9	21.7	10.4	5.2	ND	5.93
Osceola	61-76	67.6	21.0	11.4	7.4	ND	5.98
	91-107	67.5	18.2	14.3	10.1	ND	5.78

Appendix C. BULK DENSITY (D_b) OF SOILS OF MAJOR STUDY PLOTS

Plot	Site	Surface		Subsoil		Substratum	
		Depth (cm)	D_b (gm/cc)	Depth (cm)	D_b (gm/cc)	Depth (cm)	D_b (gm/cc)
DW	1	0-46	1.09	41-157	1.46	--	--
DW	2	0-43	1.13	43-147	1.64	147-267	1.57
DW	3	0-51	1.13	51-157	1.94	--	--
NE 13		0-50	1.07	50-189	1.61	189-272	1.53
S 22		0-20	1.20	20-145	1.53	145-290	1.70
SF		0-61	1.05	61-160	1.53	160-277	1.47
UCC		0-25	1.40	25-152	1.69	152-250	1.68
CP		0-27	1.12	27-80	1.65	--	--
BP		0-29	0.74	29-147	1.17	147-284	1.57
TUNE		0-28	1.18	28-90	1.67	--	--
COO		0-51	1.15	51-149	1.68	--	--
GVC		0-29	1.11	29-156	1.85	150-246	2.10
NEGV		0-22	1.31	22-150	2.15	--	--
SV		0-14	1.24	14-55	1.56	--	--
HV		0-13	1.46	13-117	1.77	--	--
BL		0-55	1.15	55-147	1.67	147-255	1.74
SC	1	0-25	1.30	25-110	1.80	--	--
SCR		0-20	1.19	20-145	1.75	145-234	1.73

Appendix D. EXCHANGEABLE AND SOLUBLE CATIONS OF SURFACE SOILS

Plot	Site	Depths (cm)	Exchangeable Cations				Soluble Cations			
			Ca	Mg	K	Na	Ca	Mg	K	Na
				(Meg/100g)			(Meq/100b)		1:1 Extract	
DW	1	0-24	3.64	0.72	0.499	0.032	0.028	0.011	0.018	0.012
DW	2	0-19	5.46	1.30	1.970	0.055	0.018	0.008	0.049	0.006
DW	3	0-25	2.92	0.59	0.482	0.030	0.020	0.010	0.019	0.013
NE 13		0-24	5.25	0.79	0.655	0.020	0.023	0.010	0.019	0.008
S 22		0-20	6.72	1.08	0.613	0.099	0.024	0.008	0.017	0.010
SF		0-15	7.31	1.39	0.493	0.006	0.073	0.029	0.020	0.014
UCC		0-25	4.87	1.23	0.566	0.081	0.023	0.010	0.015	0.009
CP		0-27	8.18	3.01	1.240	0.088	0.053	0.034	0.038	0.012
BP		0-29	10.44	2.78	0.914	0.052	0.060	0.031	0.027	0.012
TUNE		0-28	5.33	1.04	0.767	0.026	0.041	0.016	0.051	0.021
COO		0-24	10.47	2.06	1.140	0.076	0.057	0.019	0.039	0.006
GVC		0-29	3.75	0.79	0.352	0.018	0.016	0.004	0.010	0.007
NEGV		0-22	5.28	0.84	0.370	0.045	0.030	0.010	0.010	0.007
SV		0-14	6.17	1.65	0.261	0.008	0.014	0.005	0.011	0.006
HV		0-13	9.41	2.13	0.486	0.014	0.038	0.011	0.011	0.006
BL		0-28	3.32	0.44	0.266	0.028	0.034	0.015	0.011	0.006
SC	1	0-25	4.35	2.93	0.134	0.052	0.021	0.008	0.005	0.012
SC	2	0-24	13.55	2.24	0.227	0.012	0.148	0.041	0.012	0.009
SCR		0-14	9.92	1.32	0.610	0.014	0.277	0.046	0.070	0.016
BF		0-15	11.05	1.45	0.770	0.023	0.072	0.028	0.033	0.016
CAO		0-15	4.27	0.96	0.393	0.043	0.031	0.013	0.020	0.006
HB		0-15	5.00	0.88	0.520	0.015	0.024	0.009	0.015	0.008

Appendix E. EXCHANGEABLE AND SOLUBLE CATIONS OF REPRESENTATIVE SUBSOIL LAYERS

Plot	Site	Depths (cm)	Exchangeable Cations				Soluble Cations			
			Ca	Mg	K	Na	Ca	Mg	K	Na
			(meq/100 gm)							
DW	1	77-99	2.83	1.53	0.347	0.056	0.008	0.005	0.004	0.014
DW	2	67-91	2.93	1.14	0.609	0.068	0.005	0.003	0.011	0.006
DW	3	89-111	0.71	0.36	0.317	0.040	0.004	0.003	0.007	0.014
NE 13		84-109	1.79	0.52	0.529	0.033	0.007	0.003	0.008	0.007
S 22		79-99	3.47	1.54	0.340	0.084	0.008	0.004	0.008	0.009
SF		76-91	4.48	1.63	0.432	0.023	0.016	0.008	0.007	0.011
UCC		71-99	7.45	2.12	0.609	0.108	0.003	0.001	0.004	0.006
UCC		216-250	16.30	4.29	0.068	0.305	0.003	0.001	0.001	0.015
CP		64-80	6.09	2.48	1.250	0.021	0.015	0.009	0.020	0.006
BP		80-102	7.68	2.52	0.860	0.059	0.014	0.007	0.012	0.011
BP		231-264	14.35	2.97	0.134	0.215	0.006	0.002	0.001	0.019
YUN2		79-90	3.08	0.92	0.515	0.018	0.014	0.006	0.014	0.008
COO		93-110	12.89	2.66	0.155	0.121	0.011	0.003	0.002	0.009
GVC		137-156	7.38	1.27	0.045	0.180	0.003	0.001	0.001	0.013
NEGV		81-104	6.64	0.46	0.072	0.070	0.018	0.002	0.002	0.010
SV		46-55	5.57	1.01	0.142	0.006	0.009	0.002	0.006	0.009
HV		62-80	23.55	2.14	0.256	0.017	0.095	0.018	0.006	0.010
BL		103-127	1.21	0.20	0.084	0.048	0.005	0.001	0.001	0.012
SC	1	89-110	13.60	4.01	0.049	0.085	0.007	0.002	0.002	0.012
SC	2	89-112	8.12	1.52	0.119	0.025	0.077	0.028	0.005	0.007
SCR		81-104	2.59	0.40	0.505	0.011	0.016	0.004	0.016	0.008
BF		61-76	5.68	0.79	0.602	0.030	0.024	0.007	0.011	0.009
CAO		76-91	3.10	1.00	0.418	0.036	0.007	0.004	0.006	0.008
HB		91-107	3.17	0.90	0.227	0.026	0.008	0.005	0.006	0.012

Appendix F. ORGANIC CARBON (C) AND NITROGEN (N) IN THE SURFACE SOILS TO A DEPTH OF 25 cm.

Plot	Site	C (g/100g)	N (g/100g)	C/N
Dogwood	1	2.56	0.094	27.3
Dogwood	2	1.88	0.069	27.2
Dogwood	3	3.46	0.105	33.0
NE 13		2.70	0.097	27.9
S 22		1.70	0.071	23.9
Sky Forest R.S.		2.03	0.076	26.8
U.C. Conference Center		1.10	0.040	27.5
Camp Paivika		1.78	0.081	22.0
Breezy Point		2.08	0.102	20.4
Tunnel-2		1.63	0.051	32.0
Camp O-Ongo		1.72	0.122	14.1
Green Valley Creek		0.93	0.036	25.8
N.E. Green Valley		1.47	0.061	24.1
Snow Valley		0.83	0.041	20.4
Holcomb Valley		1.14	0.054	21.1
Bluff Lake		3.42	0.118	29.0
Sand Canyon	1	0.65	0.031	21.0
Sand Canyon	2	1.78	0.084	21.1
Schneider Creek		2.15	0.092	23.5
Barton Flat		2.99	0.119	25.1
Camp Osceola		1.14	0.043	26.8
Heart Bar		0.87	0.034	25.6

Appendix G. AVAILABLE SOIL WATER STORATE CAPACITY OF MAJOR STUDY PLOTS

Plot-Site	Soil Depth	Available Water		Soil Depth	Total Available Water
	(cm)	(Vol.%)	(cm)	(cm)	(cm)
Breezy Point	152	15.4	23.4	256	39.2
Sky Forest	152	14.3	21.8	208	30.6
Green Valley Creek	152	14.3	21.7	203	28.9
Bluff Lake	152	13.9	21.2	223	28.4
Dogwood-2	152	13.5	20.6	267	29.0
Dogwood-1	152	13.4	20.4	Not sampled	
NE 13	152	12.9	19.6	272	37.4
U.C. Conf. Cen.	152	12.4	18.9	269	27.9
Dogwood-3	152	12.2	18.5	Not sampled	
S 22	152	10.6	16.1	208	18.4
Schneider Creek	152	8.9	13.5	221	28.8
Camp O-Ongo	152	8.6	13.1	152	13.1
Sand Canyon	152	7.7	11.7	262	13.8
Tunnel-2		12.5		86	10.8
NE Green Valley		10.3		121	12.4
Camp Paivika		8.1		80	6.5
Holcomb Valley		8.4		116	9.7
Snow Valley		16.3		61	9.9
Range		7.7-15.4	11.7-23.4		6.5-39.2
Mean		11.9	18.5		21.6

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

LAKE-ARROWHEAD-FIRE 140 34-14-55 117-11-10 5250 22E 2N 3W 1892-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	76 76	76 76	76 76	77 76	76 76	76 76	74
MEAN	1.47 3.15	3.45 1.01	6.08 0.14	7.36 0.11	7.27 0.26	6.51 0.54	37.22
S.D.	1.83 3.62	4.78 1.35	6.69 0.26	7.58 0.28	7.14 0.47	6.07 1.37	16.29
S.E.	0.21 0.41	0.55 0.15	0.77 0.03	0.86 0.03	0.82 0.05	0.70 0.16	1.89
C.V.	125 115	139 133	110 191	103 251	98 179	93 255	44

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

ARROWHEAD-RANGER-STATION 107 34-14-20 117-11-25 5593 27D 2N 3W 1957-75

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	18 18	18 18	18 18	18 18	18 18	18 18	18
MEAN	1.18 4.57	5.88 1.26	7.40 0.27	6.98 0.18	7.30 0.38	5.36 0.63	41.39
S.D.	1.40 5.13	7.38 1.15	8.66 0.37	9.22 0.50	9.06 0.51	4.29 1.04	20.58
S.E.	0.33 1.21	1.74 0.27	2.04 0.09	2.17 0.12	2.14 0.12	1.01 0.25	4.85
C.V.	118 112	125 91	117 138	132 271	124 135	80 166	50

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

LAKE-ARROWHEAD-FD4 280 34-15-40 117-12-10 5205 16E 2N 3W 1970-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	5 5	5 5	5 5	5 4	4 4	5 4	3
MEAN	1.35 1.32	3.49 1.07	7.86 0.11	3.35 0.06	5.34 0.05	6.26 0.26	25.98
S.D.	1.50 1.48	2.45 1.01	6.89 0.24	3.18 0.12	8.04 0.08	5.34 0.30	1.92
S.E.	0.67 0.66	1.09 0.45	3.08 0.11	1.42 0.06	4.02 0.04	2.39 0.15	1.11
C.V.	110 113	70 95	88 224	95 200	150 185	85 118	7

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

SQUIRREL-INN-#1 149 34-13-10 117-14-40 5239 25H 2N 4W 1893-65 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	46 48	46 47	46 46	47 47	46 47	49 46	41
MEAN	1.56 3.58	2.61 1.88	5.25 0.27	7.09 0.13	6.81 0.18	6.51 0.60	37.83
S.D.	1.85 3.79	2.98 2.36	6.03 0.65	8.61 0.73	5.62 0.33	4.91 1.37	14.21
S.E.	0.27 0.55	0.44 0.34	0.89 0.10	1.26 0.11	0.83 0.05	0.70 0.20	2.22
C.V.	119 106	114 126	115 237	121 555	83 184	75 229	38

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

LAKE-GREGORY 221 34-14-24 117-16-12 4535 23 2N 4W 1960-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	15	15	15	15	15	14	
	14	13	15	13	14	14	13
MEAN	1.04	5.16	5.94	5.18	5.39	4.82	
	3.43	0.86	0.26	0.09	0.21	0.89	33.79
S.D.	1.10	5.28	7.23	7.90	6.71	3.29	
	4.19	0.71	0.31	0.21	0.38	2.03	17.48
S.E.	0.28	1.36	1.87	2.04	1.73	0.88	
	1.12	0.20	0.08	0.06	0.10	0.54	4.85
C.V.	106	102	122	153	124	68	
	122	82	121	226	176	229	52

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

SQUIRREL-INN-#2 47 34-13-40 117-14-50 5680 30B 2N 3W 1929-74 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	45	45	45	45	45	45	
	45	45	45	45	45	45	45
MEAN	1.54	3.99	6.95	7.36	7.85	6.15	
	3.69	1.03	0.15	0.11	0.23	0.70	39.76
S.D.	2.16	5.06	6.25	6.93	7.61	6.09	
	3.97	1.61	0.28	0.22	0.38	1.74	16.19
S.E.	0.32	0.75	0.93	1.03	1.13	0.91	
	0.59	0.24	0.04	0.03	0.06	0.26	2.41
C.V.	141	127	90	94	97	99	
	108	155	184	204	162	248	41

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

CRESTLINE-FIRE#2 284 34-14-20 117-17-30 4880 22M 2N 4W 1966-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	8 7	9 8	9 8	7 9	8 8	7 8	6
MEAN	1.08 2.07	4.55 0.95	7.21 0.30	3.12 0.10	3.62 0.12	5.53 0.21	29.94
S.D.	1.29 3.29	3.06 0.89	8.11 0.34	2.65 0.21	4.73 0.11	3.68 0.34	13.83
S.E.	0.46 1.24	1.02 0.32	2.70 0.12	1.00 0.07	1.67 0.04	1.39 0.12	5.64
C.V.	120 159	67 94	113 113	85 203	131 91	67 165	46

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

CRESTLINE-SE 181 34-14-00 117-16-59 5160 27G 2N 4W 1956-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	19 19	19 19	19 20	19 20	19 20	19 20	19
MEAN	1.10 3.72	4.52 1.37	6.01 0.27	6.57 0.10	6.51 0.16	4.63 0.75	35.76
S.D.	1.19 4.31	5.51 1.81	6.75 0.30	7.79 0.21	7.58 0.26	3.68 1.74	15.74
S.E.	0.27 0.99	1.26 0.41	1.55 0.07	1.79 0.05	1.74 0.06	0.85 0.39	3.61
C.V.	108 116	122 132	112 111	119 214	116 162	80 232	44

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

PILOT-ROCK-CONSV-CAMP 220 34-16-20 117-17-10 3688 10K 2N 4W 1960-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	15	15	15	15	15	15	15
	15	15	15	15	16	16	
MEAN	0.75	4.89	5.81	4.81	5.81	4.08	30.49
	2.80	0.57	0.07	0.06	0.25	0.64	
S.D.	0.88	5.46	6.26	7.13	9.38	3.68	15.82
	4.16	0.56	0.12	0.15	0.61	1.54	
S.E.	0.23	1.41	1.62	1.84	2.42	0.95	4.09
	1.07	0.15	0.03	0.04	0.15	0.39	
C.V.	117	112	108	148	162	90	52
	149	99	169	242	248	240	

Appendix 4. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

BIG-BEAR-LAKE-DAM 32 34-14-30 116-58-30 6815 22 2N 1W 1883-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	92 92	92 92	92 92	92 92	92 92	92 92	92
MEAN	1.45 3.04	3.18 1.15	5.79 0.17	7.08 0.45	7.05 0.79	6.51 0.70	37.36
S.D.	2.13 3.46	4.03 1.71	6.38 0.48	7.48 0.68	7.50 0.97	6.07 1.19	16.29
S.E.	0.22 0.36	0.42 0.18	0.66 0.05	0.78 0.07	0.78 0.10	0.63 0.12	1.70
C.V.	147 114	127 149	110 281	106 152	106 122	93 170	44

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

CRESTLINE-CO-YARDS 176 34-14 117-18 4920 28 2N 4W 1957-75 M

	OCT	NOV	DEC	JAN	FEB	MAR	
	APR	MAY	JUN	JUL	AUG	SEP	ANNUAL
N	17	17	16	16	16	16	
	16	17	16	15	15	16	13
MEAN	1.09	4.43	4.97	5.40	5.82	4.61	
	2.83	2.71	1.77	0.06	0.11	0.50	35.64
S.D.	1.30	4.96	7.10	8.87	6.92	3.56	
	3.06	5.54	5.79	0.17	0.27	0.70	21.25
S.E.	0.31	1.20	1.77	2.22	1.73	0.89	
	0.76	1.34	1.45	0.04	0.07	0.18	5.90
C.V.	119	112	143	164	119	77	
	108	204	327	310	232	140	60

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

PANORAMA-POINT 130 34-13-31 117-18-32 3775 2N 4W 28 1959-75

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	15	15	15	15	15	15	
	15	15	15	15	15	15	15
MEAN	0.74	4.59	5.12	6.03	5.19	3.80	
	2.64	1.09	0.51	0.08	0.13	0.54	30.46
S.D.	0.94	5.19	6.11	8.86	7.57	2.64	
	3.45	0.84	0.48	0.15	0.19	1.19	16.43
S.E.	0.24	1.34	1.58	2.29	1.96	0.68	
	0.89	0.22	0.12	0.04	0.05	0.31	4.24
C.V.	127	113	119	147	146	70	
	130	77	93	201	146	220	54

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

BIG-BEAR-LAKE-FIRE 90 34-14-40 116-54-35 6745 20E 2N 1E 1950-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	25 25	25 25	25 25	25 25	24 25	25 25	24
MEAN	0.54 1.93	2.58 0.46	3.57 0.11	4.47 0.76	3.22 0.78	3.09 0.62	21.26
S.D.	0.73 2.34	3.18 0.61	4.54 0.33	5.23 0.89	4.32 1.00	2.49 1.00	10.11
S.E.	0.15 0.47	0.64 0.12	0.91 0.07	1.05 0.18	0.88 0.20	0.50 0.20	2.06
C.V.	136 121	123 132	127 308	117 118	134 129	81 162	48

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

BIG-BEAR-CITY 91A 34-15-40 116-50-30 6800 14A 2N 1E 1955-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	20 21	20 21	20 21	20 21	20 21	20 21	20
MEAN	0.54 0.73	1.46 0.29	1.69 0.13	1.80 0.89	1.48 0.96	1.22 0.53	11.60
S.D.	0.64 0.90	1.58 0.52	1.97 0.30	2.32 0.82	1.93 1.04	1.06 0.87	4.87
S.E.	0.14 0.20	0.35 0.11	0.44 0.06	0.52 0.18	0.43 0.23	0.24 0.19	1.09
C.V.	119 123	108 182	117 222	129 92	130 108	87 165	42

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

GREEN-CANYON-SPRINGS 70A 34-14-00 116-48-10 7600 29 2N 2E 1963-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	12 13	12 13	12 13	12 13	12 13	12 13	12
MEAN	0.53 1.05	1.83 0.32	2.74 0.06	2.17 0.81	1.38 1.56	1.57 0.61	14.52
S.D.	0.66 1.15	2.08 0.63	3.11 0.12	3.58 1.10	2.50 1.66	1.17 1.14	7.14
S.E.	0.19 0.32	0.60 0.17	0.90 0.03	1.03 0.30	0.72 0.46	0.34 0.32	2.06
C.V.	125 109	114 196	114 190	164 135	181 106	74 188	49

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

GREEN-VALLEY-LAKE 264 34-14-22 117-04-42 6880 27C 2N 2W 1960-75

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	15 15	15 15	15 15	15 15	15 15	15 15	15
MEAN	0.84 2.83	5.35 0.65	5.75 0.16	5.66 0.26	5.57 0.56	4.21 0.72	32.56
S.D.	0.94 3.72	5.67 0.76	6.32 0.45	8.35 0.37	-7.06 0.64	2.64 1.63	14.44
S.E.	0.24 0.96	1.46 0.20	1.63 0.12	2.16 0.09	1.82 0.17	0.68 0.42	3.73
C.V.	112 132	106 117	110 287	147 139	127 114	63 228	44

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

HEART-BAR-STATE-PARK 259 34-9-34 116-47-43 6688 20F 1N 2E 1966-75

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	9 9	9 9	9 9	9 9	9 9	9 9	9
MEAN	0.48 1.05	1.85 0.34	3.06 0.12	2.70 1.16	2.04 1.23	2.15 0.43	16.63
S.D.	0.47 1.16	1.45 0.73	3.00 0.36	3.68 1.32	3.24 1.19	1.84 0.48	5.97
S.E.	0.16 0.39	0.48 0.24	1.00 0.12	1.23 0.44	1.08 0.40	0.61 0.16	1.99
C.V.	98 110	78 211	98 300	136 114	159 97	85 112	36

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

CAMP-ANGELUS-SPENCER 260A 34-09-00 116-58-40 5860 28A 1N 1W 1967-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	8 9	8 9	8 8	9 8	9 9	9 8	7
MEAN	0.96 3.01	3.77 0.94	4.04 0.14	6.48 0.95	5.05 1.11	5.10 0.31	30.25
S.D.	1.01 2.91	3.04 0.81	3.17 0.33	10.62 0.84	8.61 0.97	3.40 0.42	19.99
S.E.	0.36 0.97	1.07 0.27	1.12 0.12	3.54 0.30	2.87 0.32	1.13 0.15	7.55
C.V.	105 97	81 86	78 231	164 88	171 87	67 135	66

Appendix H. LONG-TERM PRECIPITATION DATA FRO 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

BLUE-JAY-CO-YARDS 104 34-13-18 117-13-42 5400 29 2N 3W 1957-61 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	5 5	5 5	5 4	5 4	5 5	5 4	4
MEAN	1.35 3.41	3.39 0.53	4.66 0.00	4.26 0.01	9.10 0.24	4.71 0.92	32.66
S.D.	1.73 3.96	2.89 0.54	5.09 0.00	1.58 0.02	6.09 0.47	5.84 0.72	22.71
S.E.	0.77 1.77	1.29 0.24	2.28 0.00	0.71 0.01	2.73 0.21	2.61 0.36	11.36
C.V.	128 116	85 102	109 0	37 200	67 199	124 78	70

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

SAN-ANTONIO-HEIGHTS 85 34-09-03 117-39-03 1901 19L 1N 7W 1892-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	84 84	84 83	84 84	84 84	84 84	84 84	83
MEAN	0.87 1.89	1.83 0.70	3.81 0.11	4.45 0.03	3.93 0.06	3.91 0.31	21.93
S.D.	1.08 2.06	2.53 0.99	4.03 0.22	4.90 0.14	3.74 0.16	3.38 0.77	8.70
S.E.	0.12 0.22	0.28 0.11	0.44 0.02	0.54 0.02	0.41 0.02	0.37 0.08	0.95
C.V.	124 109	138 141	106 206	110 423	95 279	86 247	40

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

SAN-BERNARDINO-CO-HOSP 146 34-08 117-16 1125 34K 1N 4W 1870-75 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	105 105	105 105	105 104	105 105	105 104	105 105	103
MEAN	0.71 1.43	1.40 0.55	2.71 0.10	3.20 0.03	3.09 0.14	2.65 0.24	16.23
S.D.	0.86 1.48	1.67 0.67	2.59 0.19	2.82 0.08	2.82 0.34	2.30 0.59	6.22
S.E.	0.08 0.14	0.16 0.07	0.25 0.02	0.28 0.01	0.27 0.03	0.22 0.06	0.61
C.V.	121 103	119 122	96 196	88 227	91 246	87 242	38

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

JOBS-PEAK 115 34-15-20 117-20 5160 17 2N 4W 1958-65 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	7 7	8 7	8 7	8 6	8 7	8 8	5
MEAN	0.59 3.12	4.98 0.48	2.91 0.20	2.22 0.06	4.17 0.00	1.82 1.01	22.46
S.D.	0.80 3.77	7.29 0.68	3.46 0.29	1.21 0.14	4.28 0.00	0.98 2.06	9.56
S.E.	0.30 1.42	2.58 0.26	1.22 0.11	0.43 0.06	1.51 0.00	0.35 0.73	4.28
C.V.	137 121	146 142	119 140	55 245	103 0	54 204	43

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

CEDAR-PINES-PARK 112 34-15 117-20 4750 1951-56 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	6 6	6 6	5 6	6 6	6 6	6 6	5
MEAN	0.58 3.32	3.57 1.39	4.20 0.08	9.39 0.08	3.94 0.13	5.85 0.20	33.53
S.D.	0.87 2.01	1.56 1.75	4.30 0.08	6.49 0.16	2.23 0.18	5.99 0.33	13.66
S.E.	0.36 0.82	0.64 0.72	1.92 0.03	2.65 0.07	0.91 0.07	2.45 0.14	6.11
C.V.	150 61	44 126	102 98	69 210	57 134	102 170	41

Appendix H. LONG-TERM PRECIPITATION DATA FOR 24 SAN BERNARDINO MOUNTAIN STATIONS. (SAN BERNARDINO COUNTY FLOOD CONTROL DISTRICT)

RUNNING-SPRINGS 62 34-12-16 117-6-5 6230 4 1N 2W 1942-69 M

	OCT APR	NOV MAY	DEC JUN	JAN JUL	FEB AUG	MAR SEP	ANNUAL
N	26 26	26 26	25 26	25 26	25 26	26 26	24
MEAN	1.01 3.31	4.47 1.05	5.00 0.08	7.38 0.25	7.80 0.34	4.97 0.61	36.75
S.D.	1.59 3.24	6.03 1.35	4.78 0.13	8.59 0.37	9.06 0.55	4.54 1.22	17.51
S.E.	0.31 0.63	1.18 0.26	0.96 0.03	1.72 0.07	1.81 0.11	0.89 0.24	3.57
C.V.	158 98	135 129	96 166	116 149	116 160	91 200	48

Appendix I. AMBIENT AIR QUALITY STANDARDS

		California Standards[*]		National Standards[**]		
Pollutant	Averaging time	Concentration[+]	Method[‡]	Primary[+#]	Secondard[+##]	Method[‡‡]
Oxidant (ozone)	1 hour	0.10 ppm (200 μg/m³)	Ultraviolet photometry	160 μg/m³ (0.08 ppm)	Same as primary standard	Chemi-luminescent
Nitrogen Dioxide	Annual average	---	Saltzman Method	100 μg/m³ (0.05 ppm)	Same as primary standard	Proposed modified J H Saltzman (O3 corr.)
	1 hour	0.25 ppm (470 μg/m³)		----		Chemiluminescent

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[*] California standards are values that are not to be equaled or exceeded.

[**] National standards, other than those based on annual averages or annual geometric means, are not to be exceeded more than once per year.

[+] Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 mm of mercury. All measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 mm of Hg (1,013.2 millibar); ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

[‡] Any equivalent procedure which can be shown to the satisfaction of the Air Resources Board to give equivalent results at or near the level of the air quality standard may be used.

[#] National Primary Standards: The level of air quality necessary, with an adequate margin of safety, to protect the public health. Each state must attain the primary standards no later than three years after that state's implementation plant is approved by the Environmental Protection Agency (EPA).

[##] National Secondary Standards: The levels of air quality necessary to protect the public welfare from any known or anticipated adverse effects of a pollutant. Each state must attain the secondary standards within a "reasonable time" after implementation plan is approved by the EPA.

[‡‡] Reference method as described by the EPA. An "equivalent method" of measurement may be used but must have a "consistent relationship to the reference method" and must be approved by the EPA.

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA

Location	Jan.	Feb.	March	April	May	June	July 1967	Aug.	Sept.	Oct.	Nov.	Dec.
Crestline												
Oxidant								10-14 17,31	1-10, 12,16-28 **			
Arrowhead Golf Course												
Oxidant										3-15, 21,26-30	1-7	
Heap's Peak												
Oxidant								5,6 8-11 15-18, 22,26-28,30	1-4, 6-19, 21-30			
Temperature*								1,2, 4-11	14-26, 28-30			
Wind speed*								1,2, 4-11	14-26, 29,30			
Wind Director* Distance								1-12	13-30			
Wind Direction* Hourly Average								1,2, 4-11	14-30			
Rock Camp												
Oxidant										3,4, 11-20, 22-30	2-7	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1967												
Rock Camp												
Wind Speed*										19-23, 26-31		
Wind Direction* Distance										18-31		
Wind Direction* Hourly Average										19-31		
Temperature*										19-24, 26-31		
1975												
Rock Camp												
Oxidant						8-31						

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							1967					
Rim Forest												
Oxidant								10-14, 17,22, 29-31	1,3-16,18-27	7,9-16,18-23,26 28-31	9-17	
							1968					
Rim Forest												
Oxidant					15-31	1-11, 14-20, 24-30	1-7 9-14, 17-18, 20-21, 23-29	1-5, 8-21, 25-26, 28-30	1-15, 17-24	10,16-27		
							1969					
				15-17, 19-21 23-24, 26-30	1,12-27,31	1-17, 27-30	1-8, 10,13, 17-22, 25-29 31	1-3, 5-23, 25-31	1,6-19,22-28	1-31	1-24	
							1970					
				8-24, 26,29-30	1-5 7-12, 16-20, 23-31	1-3, 6-24, 20-30	1-11, 13-15, 18-24, 28	7-22, 25-31	1-3, 9-12, 15,17-21,25, 26	3-7, 10-22		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1971						
Rim Forest* High School						2-18, 21-30	1-20, 22,24-31	1-15, 31	9,16-30	1-5		
Rim Forest Burke Station					3-8, 11-27	2-30	1-31	1-15, 17-22, 25-31	7-30	1-3, 5,9, 11-28		
						1972						
Rim Forest					2-8, 11-18 23-21	1-9, 13-14, 21-25, 30	1-5, 8-11, 18-31	1-29, 31	1-7, 9-18, 21-28			
						1973						
				17-18, 24-29	1-20, 23-31	1-6, 9-18, 26-30	1-5, 7-31	1-5				
						1969						
Atlantic Avenue												
Oxidant					22-24, 26-30	1,3-4,6-7,21-24,26, 29,30	3-11, 15,22-31	1-12, 16-23 31	1-3, 8-13, 19,24, 27-28			
City Creek Oxidant					17,22-31	1-5, 7-28	10,17 20-31	1-28				

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							1969					
Mud Flats Station												
Oxidant					22,29	3-4, 7-12, 21	5,8- 9,12, 14,15, 19-21, 29-31	9,12, 15,19				
							1972					
Barton Flats												
Oxidant						7-8, 10-13, 17-27	8-11, 18-19, 25-31	1-5, 8-12, 14-15, 17-20, 22-26, 29-31	1-10, 12-30			
							1973					
Oxidant					19-31	1-3, 5-6, 16-17, 19-30	1-19, 21,24- 29	3-29	1-2 6-8, 11-23, 25-30	6-23 25-31	1,6- 17	
							1974					
Oxidant					4-12, 14-31	1-15, 17-30	1-12, 14-18, 20-23, 26-31	2-3, 6-31	1-3, 5-12, 14-21, 23-25, 27-30	1-17, 20-28 30		
Temperature Centigrade								1 ,4 6,7	1-2, 10,13- 19,24, 28-30	3 -5, 12,15, 17-21, 23-24		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1974							
Barton Flats Wind Speed								1,7	24-28 30	4,5 12-15 17-21 23-24		
Wind Direction								1,4 6-7	1,2 10,13- 19,24 28-30	3-5 12-15 17-21 23-24		
Net Radiation								4	13,14 18,19 24,28 29	18,19 23,24		
					1975							
Barton Flats Ozone				30	1-31	1-30	1-9 11,17 20-25 27,31	1-3 5-24 30,31	1-7 9-14 16-30	1-6		
Temperature Centigrade						8-9 12-15 18-23 26,27 29,30	1-11 16,17 20-27	26-31	1,3- 30	1-6 8-28	1-3	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1975							
Barton Flats												
Relative Humidity					23-26	8,9 12-15 22,26 27,29 30	1-8 16-18 20-25 27	27-31	3-8 10-14 17-30	1-6 8-21 23-28	1-3	
Wind Speed					23-26	8,12 14,15 19,21 22,27 29	1,2 5,6 8-11 17,20 22,25 27			22,24 26-29		
Wind Direction					23-26	8,9 12-15 18-23 26,27 29,30	1-11 16-18 20-27			22,24 26,27		
Net Radiation						8,9				22,26- 29		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1976							
Barton Flats Ozone					5-7	26	3,8, 13-31	1,3- 15,17 19,21 28-31	1,2 4,5 8-14 16-23 25-30	1-21 24,29 31	1	
Oxidant					28-31	8-30	1-5 7,8 10-13	26				
Temperature Centigrade					23	12,15 19,20		11,18- 20,22 23,27 29		11,12 17,31		
Relative Humidity					23	12,15 19		11,18- 20,22 23,27 29		11,12 17,31		
Wind Speed					23	19		11,18- 20,22 27,29		11,12 31		
Wind Direction					23	12,15 19		11,18- 20,22 23,27 29		11,12 17,31		
Net Radiation					data not valid							

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1972						
Fawnskin Oxidant						23-30	1-7, 9,12, 18-22, 25	3,8- 17,22- 31	1-30	1-19, 21-26		
Green Valley Lake Oxidant						20-30	1-12, 18-24, 29-31	1,5, 8-10 14-20, 29-31	5-17, 28-30	1-5, 7-15, 19-21 26		
Heart Bar Oxidant						24-29	6-11, 25-31	4-8, 10-21, 23-31	1-7, 19-22, 30	1-3, 21-23, 26		
						1975						
Oxidant							13,23- 28,31	13-17, 19,24- 31	1-6, 13-15	2-7, 9-14, 18-31	1	
						1976						
Oxidant					5,6, 8-16 19-23, 27,28	2-9, 15-27	1-18, 21-31	1-5, 10-31	1-6, 8,14, 23-30	1,5- 7,13- 21		
						1972						
Placerville* Oxidant						1-30	1-31	1-9, 25-28	2-5, 7-10, 13-16, 19-22, 25-28			

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1972						
Camp Angelus												
Oxidant						22-26	1-4, 8,9, 22-27	3-9, 18-31	1-20 26-30			
						1974						
Oxidant						8,11-20,22-24,27-29	2-18, 21-25	1-3, 8,13	4-30	1-5, 8-20 30		
						1975						
Oxidant								14-26,	6-19, 21,24-27	11-12, 24-30		
Temperature*								14-17, 21-24, 27-31	1-4, 9-21, 25-28, 30	1-19, 25-26 28-31	1,2	
Relative Humidity*								14-17, 21-24, 27-31	1-4, 9-21 25-28 30	1-19, 25-26, 28-31	1,2,	
						1976						
Oxidant				29,30	1-3, 5-27	2-5, 8-14, 23-27, 30	1-5, 11,14, 17-19, 22-29, 31	1,3-31	1-5, 7-13, 15-30	1-31		
Temperature*					19-30	2-30						
Relative Humidity*					19-31	2-19 22-30						

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1973						
Placerville* Oxidant				3,8-11,13-15,17-23,26-30	1-5, 8-10, 15-21, 24-27 30-31	2,5,7, 10,14-18,21-30	3-6, 24-26 28	7-8, 10,14, 15,21-29	1,5-12,15-24,27, 28	1-12		
Big Bear Ranger Station								25-31	1-2, 4-22, 25-30	1-9, 11-28,	1-5, 9-11, 15-17, 19-20	
Sky Forest Oxidant								7-31	1-12, 14-16, 19-24	2-31	1-19, 22-30	
PAN*								10-13, 21,29	7-8, 26-29	1-11, 13-31	1-12	
NO_2*								17,25, 28,30	20,22 25-30	1,17-24,30-31	1-21, 24-25 27-30	1-3, 8,11-14,20, 29,29-31
Temperature								13-20	25-30	1-23		
Wind Direction								13-20	25-30	1-23		
Wind Speed								13-20	25-30	1-23		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May 1974	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Sky Forest												
Oxidant	1-6 31	7-28	1-8 12-31	1-24 27-30	1-19 23-31	1-30	1-9 11-31	1-31	1-3 5-30	1-7 10-26	3-25 28-30	1-3 6-12 20-22 28-31
Temperature Centigrade							30,31	1,3- 7,9- 21,31	1-5 10,13- 30	3-6 12-21 23-28 31	1,2	
Relative Hunidity					data not valid							
Wind Speed								3-7 9,10 12,13 15,16	1,2, 4,5 13,15- 30	3-6 12-19 21,23- 27		
Wind Direction							30,31	1,3- 7,9- 21,31	1-5 10,13- 30	3-6 12-31 23-28 31	1,2	
Net Radiation							30,31	1,3 4,31	1-5 10,16- 30	3-6 12-28	1	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED)

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1975							
Sky Forest												
Ozone	9-13 15,24- 27,29- 31	1-16 21,22 25-28	1-5 15-31	1-7 9-15 17-30	1-31	1-30	1-31	1-31	1,2, 4,30	1-14 18-31	1-12 14-30	1-14 17-31
Oxidant	1-15 17-31	1-3 5-9 11-28	1-12 15-31	1-16 26-28	2-21 26,31	1-3 6-9 13-16						
Temperature	2-15 17-31	1-28	1-9 11-31	1-30	1-31	1-30	1-31	1-31	1-30	1-31	1-15 19,20 22-30	1-7 20-31
Relative Humidity					23-26 29,31	1,2 5,9 11-15 21,22	23,26 31	1-10 12-27 29-31	1-8 10,12 14,16 18,19 22-25 27,28	4,5 8-15 17,22- 24,26- 29	1-5	
Net Radiation						3,6 18,19	10,11 17,25- 28	3,4 20,27- 29,31	1-8 10,12 14,16 28,29	4,5 8-12 22-24 26-30	3-5	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1975												
Sky Forest												
Wind Speed					23-26 29-31	1-9, 11-16, 18-23, 26,27, 29,30	1-29, 31	1-10, 12-31	1-8, 10,12, 14,16, 18,19, 22-25, 27,28	4,5, 8-15, 17,22-24,26-31	1-5	
Wind Direction					23-26 29-31	1-9, 11-16, 18-23, 26,27, 29,30	1-29, 31	1-10, 12-31	1-8, 10,12 14,16, 18,19, 22-25 27,28	4,5, 8-15 17,22-24,26-31	1-5	
1976												
Ozone	1,2, 4-22	3-5, 7-29	1-22, 26-31	1-19	4-23 26-31	2-21, 23-29	2-7, 10-31	1,2, 5-23 28-31	1-30	2-20, 22-31	1-11, 16,19-25,29, 30	1-21, 25-31
Temperature*	1-31	1-6, 8-29	1-21, 24-31	1-28,	1-31	1-7						
Temperature Centigrade					22,23 29	8,10-13,15-17,19 20,23 26,27 30	3-5 7-16 18-20 23-31	1,2 4-23 26-31	1,4-10,14	8-13, 16,17 19,20 27,30 31	3,8	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1976						
Sky Forest Relative Humidity					22,23 29,31	6,8 10-13, 15-20 23,26 27,30	2-5, 7-20 23-31	1,5- 23,27- 31	1,8, 14	8-13, 16,17 19,20 27,30 31	3,8	
Wind Speed					22,23 29,31	5,6 8,10- 13,15- 17,19- 20,23 26,27, 30	2-5 7-20 23-31	1-23, 26-30	7,14	8-13 16,17 19,20 27,30 31	3,8	
Wind Direction					22,23 29,31	5,6 8,10- 13,15- 17,19- 20,23 26,27 30	2-5 7-20 23-31	1-23 26-31	1,4- 10,14	8-13 16,17 19,20 27,30 31	3,8	
Net Radiation					29	10		15,30	9,10	20		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUTED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
							1974					
Big Bear Dam Oxidant					3-16, 19,20, 22-31	1-30	1-8, 10,11 13-25	2-4, 7-27	3-30	1-30		
Big Bear APCD Ozone					1-28, 30,31	1-25, 27-30	1,3- 31	1-4, 7-28	1-12, 14-29	3,5, 7,8, 12-30		
							1975					
Ozone	6,8, 10	9,10, 12-14, 16-22 25-27	2-31	1-4, 6-30	1-20, 22-31	1,2, 4-10, 12-30	2-16, 18-21,				20,21 26-28	12-14, 23,28
Wind Speed*	9-31	1-10, 14-27	15-17, 19-31									3,4, 11-13, 20-31
							1976					
Ozone	9,19- 21,24	3-5, 7,8, 10,14- 16,18- 20,23, 24,29	8,9, 15-19 22-31									
							1974					
Lake Gregory APCD Ozone					7-12, 21-23, 25,26	1-5,7 9-22, 30	1,3- 7,11- 18,27- 31	1-11, 14-24	5-21, 24-30	1-24, 31		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1975						
Lake Gregory APCD Ozone	2,8, 11,12, 17,18, 26,27, 29	1,2, 4,8-10,12-14,16, 17,19-28	1-3, 8-16, 18,19, 22,26-29	2-3	1-13, 15-18 22-31	1-11, 13-17, 19-30	1-6, 8-10, 12-16, 18-28					6,7, 16,25, 28,30, 31
Wind Speed*	4-12, 14-29, 31	1-4, 7-17, 19-28	1,4-15,17, 22,27, 30	1-22, 26,30	1-11, 13-28, 31		1-14, 17-29					1-4, 9-28, 31
						1976						
Ozone	2,6 9,15, 19-21, 25,27, 28	2-10, 14-16, 18-20, 23,25, 27-29	1-3, 8-12, 14,19, 22,23-31									
						1974						
Camp Paivika Ozone					24-26, 30,31	1-9, 11-12, 18,19, 21-30	1-7, 9-15, 30,31	1-31	1-30	1-3, 5,6, 8-10, 12-21, 23-27		
Relative Humidity										5,6 20,21 23,24	4	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1974							
Camp Paivika												
Temperature							30,31	1,3 4,6 9,21 31	1-5 10,13- 30	3,5 6,10 12-21 23-28 31	1,3 4	
Wind Speed							30,31	1,3 4,6 9,20 31	1-5 10,13- 30	3,5 6,10 12-21 23-28 31		
Wind Direction							30,31	1,3 4,6 9-21 31	1-5 10,13- 30	3,5 6,10 12-21 23-28 31	1-4	
Net Radiation							2,4,6 13-15 18,20 21					
					1975							
Camp Paivika												
Ozone				30	1,2 13-18	1-10 24-27 29,30	1-31	1-31	1-30	1-19 22-31	1-3	
Temperature Centigrade					23-26 28-31	1-9 11-16 18-23 26,27 29,30	1-29 31	1-10 12-31	1-10 12,14 16-25 27-30	1,4-6 8-15 22-24 26-31	1-5	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1975												
Camp Paivika												
Relative Humidity					23-26 28-31	1-16 26-30	1-13 29,31	1-10 12-31	1-10 12,14 16-25 27-30	1,4- 15,17 22-24 26-31	1-5	
Wind Speed					23-26 29-31	1-16 18-23 26,27 29,30	1-29 31	1-31	1-10 12,14 16-18 20-25 27-30	1,4- 14,17 22-24 26-31	1-5	
Wind Direction					23-26 29-31	1-9 11-16 18-23 26,27 29,30	1-29 31	1-10 11-31	1-10 12,14 16-25 27-30	1,4- 15,22- 24,26- 31	1-5	
Net Radiation						18,19		20	8,16	6,7,11 12,22 26-30	5	
1976												
Camp Paivika												
Ozone					1-4 19-22 27-31	1-8 12-14 17-30	1-7 9-20 23-31	1-13 18,19 25-31	1-9 17-30	1-13 16-21		
Oxidant								22,23	14,15	28-31		

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
					1976							
Camp Paivika Temperature Centigrade					22,31	5,6,8 10-13 15-17 19,20 23,26 27,30	2-5 7-13 16-20 23-26	1-20 22,23 26-31	1,4- 10,14	8-13 16,17 19,20		
Relative Humidity					22,31	6,10- 13,15- 17,19 20,23 26,27 30	2-5 7-13 16-19	11-20 22,23 27-31	1,4- 9,14	16,17 19,20		
Wind Speed					22,31	5,6,8 10-13 15-17 19,20 23,26 27,30	2-5 7-13 16-20 23-26 28-31	1-20 22,23 26-31	1,4- 10,14	8,10- 13,16 17,19 20		
Wind Direction					22,31	5,6,8 10-13 15-17 19,20 23,26 27,30	2-5 7-13 16-20 23-26 28-31	1-9 12-20 22,23	1,4- 10,14	16,17 19,20		
Net Radiation						10	25,26	15	7-10			

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1974						
Running Springs												
Oxidant						11-13, 15-30	1-18, 22-28	1-25, 28-31	1-10, 14-23 26-30	1-27		
						1975						
Oxidant					6-20	12-19, 24-30	1-5, 7-9, 17-24, 31	1-11, 13-31	1,2, 4,6-11,13-30	1-6, 8-10, 12-22	1,2,	
						1974						
Snow Valley												
Oxidant					3-5, 7-14, 19,21-23,25-31	1-30	1-21, 23-30	1-4, 6-8, 10-15, 17-20	1-26, 28-30	1-27, 29-30		
						1975						
Snow Valley												
Oxidant					7-9, 12-13, 17-20 22-31	1-30	1-3, 5,7-11,13-20,25-27	6,7, 9,12 19,21-31	1-8, 20-22, 24,26-28	2,6-15,18, 19,21-23,28-31	1	
University Conference Center												
Oxidant						27-30	1-31	1-30	1-30	1-23, 28-31	1,2,	

APPENDIX J. INDEX OF VALIDATED OXIDANT AND METEOROLOGICAL DATA (CONTINUED).

Location	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
						1976						
Deerlick					11,14 17,18 20,25 29,30	7,10 18-24 26	10-31	1-12, 17,19- 31	1-30	1-31		

*Means that data has not been stored on magnetic tapes and either exist in raw collection format or is punched on cards.

**Means that all dates listed in index are dates with twenty-four hours of data.

Appendix K. THE NUMBER OF CONES PRODUCED BY JEFFREY PONDEROSA PINES OF DIFFERENT CROWN CLASSES DURING 1973, 1974, 1975, AND 1976 (VISUAL COUNTS OF CONES WITHIN THE TREE CROWNS).

		Crown Classes						
Plot Name	Year	Dom.	Co-Dom.	Inter.	Inter. Open	Inter. Suppr.	Suppr.	Total Cones
		Number of Cones/Number of Trees						
		Part A.--Ponderosa Pine						
CP	1973	0/37	0/24	0/5	0/9	0/0	0/0	0
	1974	141/36(14)	17/24(4)	0/5	0/7	0/0	0/0	158
	1975	16/36(6)	4/24(3)	0/5	0/6	0/0	0/0	20
	1976	48/36(14)	13/23(1)	0/5	0/5	0/0	0/0	61
BP	1973	1/25(1)	0/23	0/7	0/9	0/5	0/0	1
	1974	163/25(10)	91/23(7)	0/6	0/9	0/4	0/0	254
	1975	11/25(2)	8/23(2)	0/5	0/9	0/4	0/0	19
	1976	51/25(8)	3/23(3)	0/5	0/9	0/4	0/0	54
DW	1973	0/10	0/10	0/17	0/6	0/0	0/16	0
	1974	326/10(5)	78/10(4)	0/17	0/6	0/0	0/16	404
	1975	25/10(1)	3/10(2)	0/16	0/6	0/0	0/15	28
	1976	58/10(5)	11/10(3)	0/16	2/6(1)	0/0	0/15	71
TUN 2	1973	1633/25(15)	135/20(4)	0/7	0/8	0/12	0/1	1768
	1974	1698/25(20)	437/20(10)	0/7	0/8	0/12	0/1	2135
	1975	8/25(3)	0/20	0/7	0/8	0/12	0/1	8
	1976	129/25(17)	4/20(2)	0/7	1/8(1)	0/12	0/1	134
SF	1973	102/33(16)	14/21(5)	0/24	1/15(1)	0/20	0/1	117
	1974	933/33(26)	560/21(12)	35/24(2)	8/15(1)	0/18	0/1	1536
	1975	48/33(12)	12/21(4)	0/24	1/14(1)	0/16	0/1	61
	1976	175/33(17)	12/21(4)	0/24	1/14(1)	0/14	0/1	188
UCC	1973	3/16(3)	0/25	0/12	0/9	0/4	0/0	3
	1974	408/15(11)	67/25(6)	0/12	8/9(1)	0/4	0/0	483
	1975	2/15(1)	6/25(2)	0/11	0/9	0/4	0/0	8
	1976	0/15	0/25	0/11	0/9	0/4	0/0	0

Appendix K. --CONTINUED.

Plot Name	Year	Crown Classes Number of Cones/Number of Trees Dom.	 Co-Dom.	 Inter.	 Inter. Open	 Inter. Suppr.	 Suppr.	Total Cones
COO	1973	9/30(3)	0/16	0/3	0/5	0/5	0/1	9
	1974	328/30(20)	18/16(1)	0/3	0/5	0/5	0/1	346
	1975	4/29(3)	0/15	0/2	0/4	0/5	0/1	4
	1976	171/29(14)	1/15(1)	0/2	0/4	0/5	0/1	172
CA	1973	1291/12(6)	313/28(9)	0/12	8/4(1)	0/0	0/9	1612
	1974	1254/12(12)	1398/28(21)	55/12(4)	59/4(1)	0/0	0/8	2766
	1975	73/12(4)	7/28(2)	0/12	0/4	0/0	0/8	80
	1976	2153/12(10)	842/28(15)	4/11(2)	5/4(2)	0/0	0/7	3004
CAO	1973	NO DATA TAKEN						
	1974	1137/5(5)	140/6(3)	0/12	0/1	0/0	0/5	1277
	1975	7/5(1)	33/7(2)	0/12	0/1	0/0	0/5	40
	1976	1090/5(5)	259/7(4)	2/12(1)	6/1(1)	0/0	0/5	1357
SCR	1973	NO DATA TAKEN						
	1974	4996/33(27)	611/13(11)	63/1(1)	0/1	0/0	0/0	5670
	1975	12/32(3)	2/13(1)	0/1	0/1	0/0	0/0	14
	1976	366/31(22)	411/13(11)	3/1(1)	0/1	0/0	0/0	780
BF	1973	0/17	0/29	0/38	0/10	0/0	0/28	0
	1974	557/17(6)	465/29(10)	4/35(1)	0/10	0/0	0/27	1026
	1975	4/17(2)	56/29(1)	0/34	0/10	0/0	0/27	60
	1976	314/17(7)	383/29(12)	2/30(2)	21/10(1)	0/0	4/26(1)	724
Part B.--Jeffrey Pine								
GVC	1973	447/38(22)	0/11	0/9	0/6	3/1(1)	0/4	450
	1974	3893/38(27)	2/11(1)	26/9(1)	0/6	10/1(1)	0/2	3931
	1975	15/38(8)	0/11	0/9	0/6	0/1	0/2	15
	1976	4952/38(32)	10/11(2)	152/9(2)	0/6	2/1(1)	0/2	5116
SV	1973	51/27(8)	16/25(4)	0/13	2/25(1)	0/0	0/9	69
	1974	223/27(13)	87/24(5)	1/13(11)	0/25	0/0	0/9	311

Appendix K.--CONTINUED.

Plot Name	Year	Crown Classes Dom.	Co-Dom.	Inter.	Inter. Open	Inter. Suppr.	Suppr.	Total Cones
		Number of Cones/Number of Trees						
SV	1975	0/27	0/24	0/13	0/25	0/0	0/9	0
	1976	270/27(19)	105/24(10)	0/13	3/25(2)	0/0	14/9(1)	392
NEGV	1973	113/20(10)	32/14(6)	7/17(2)	0/5	0/5	0/1	152
	1974	602/20(14)	187/14(9)	16/17(2)	5/5(2)	1/1(1)	0/1	811
	1975	204/20(16)	68/14(7)	7/17(2)	0/5	0/1	0/1	279
	1976	671/20(18)	265/14(11)	160/17(10)	58/5(3)	6/1(1)	1/1(1)	1161
BL	1973	68/19(7)	17/24(3)	0/32	0/32	0/16	0/12	85
	1974	155/19(10)	26/24(7)	0/32	1/32(1)	0/16	0/12	142
	1975	121/19(12)	36/24(5)	1/31(1)	5/32(2)	0/16	0/12	162
	1976	255/19(15)	52/22(10)	3/30(2)	23/32(10)	0/16	0/12	333
HV	1973	NO DATA TAKEN						
	1974	197/34(21)	34/37(10)	17/48(5)	0/29	0/0	0/18	248
	1975	372/34(26)	82/37(18)	4/48(2)	0/29	0/0	0/18	458
	1976	936/34(31)	341/37(26)	54/48(19)	0/29	0/0	16/18(2)	1040
SC	1973	221/27(16)	100/12(6)	0/8	1/9(1)	0/0	0/6	322
	1974	61/27(10)	1/12(1)	5/8(3)	0/9	0/0	0/6	67
	1975	1667/27(25)	178/12(11)	12/8(3)	8/9(3)	0/0	0/6	1865
	1976	1623/27(27)	549/12(11)	15/8(4)	62/9(6)	0/0	3/6(1)	2252
HB	1973	16/44(5)	2/27(1)	0/1	0/29	0/7	0/5	18
	1974	320/43(18)	18/27(5)	3/1(1)	0/29	1/7(1)	0/5	342
	1975	734/43(29)	184/27(10)	0/1	3/29(1)	0/7	0/5	921
	1976	1539/43(39)	239/27(19)	44/1(1)	75/29(13)	3/7(3)	0/5	1900
CAO	1973	NO DATA TAKEN						
	1974	27/10(4)	8/21(5)	138/22(4)	0/10	0/1	0/23	173
	1975	0/10	3/21(2)	4/22(1)	0/10	0/1	0/22	7
	1976	51/10(5)	136/21(8)	239/22(3)	0/10	0/1	0/22	426

Appendix K.—CONTINUED.

		Crown Classes						
Plot Name	Year	Dom.	Co-Dom.	Inter.	Inter. Open	Inter. Suppr.	Suppr.	Total Cones
		Number of Cones/Number of Trees						
BF	1973	0/14	0/21	0/29	0/5	0/0	0/17	0
	1974	23/11(1)	48/21(3)	0/29	0/5	0/0	0/17	71
	1975	1/10(1)	0/21	0/28	0/5	0/0	0/17	1
	1976	16/10(3)	11/20(3)	0/26	0/5	0/0	0/16	27
SCR	1973	NO DATA TAKEN						
	1974	110/3(3)	0/0	0/0	0/0	0/0	0/1	110
	1975	2/3(1)	0/0	0/0	0/0	0/0	0/1	2
	1976	14/3(1)	0/0	0/0	0/0	0/0	0/1	14

*Number in parenthesis is number of trees in that crown class which produced cones.

Appendix L. TAXONOMIC LIST OF SOIL MICROARTHROPODS COLLECTED FROM THE BREEZY POINT, SNOW VALLEY AND NEGV STUDY PLOTS, 1973-74.

- Insecta
  - Protura
  - Campodeidae
  - Japygidae
  - Lepismatidae
  - Collembola
    - Istomidae
    - Entomobryidae
    - Poduridae
    - Onychiuridae
    - Sminthuridae
  - Thysanoptera
  - Pscocoptera
  - Hymenoptera
  - Diptera
  - Coleoptera
    - Staphylinidae
    - Silphidae
    - Curculionidae
    - Lathridiidae
  - Raphidiidae
- Myriapoda
  - Diplopoda
  - Chilopoda
    - Geophilidae
    - Scutigeromorpha
  - Symphyla
  - Pauropoda
- Arachnida
  - Araneida
  - Chelonethida
  - Acarina
    - Prostigmata
      - Labidostomidae
      - Eupodidae
      - Bdellidae
      - Nanorchestidae
      - Stigmaeidae
      - Cunaxidae
      - Ragidiidae
      - Erythraeidae
      - Anystidae
      - Neophylobiidae

Appendix L. TAXONOMIC LIST OF SOIL MICROARTHROPODS COLLECTED FROM THE BREEZY POINT, SNOW VALLEY, AND NEGV STUDY PLOTS, 1973-74 (Continued)

- Arachnida (continued)
    - Tydeidae
    - Cryptognathidae
    - Raphignathidae
    - Cheyletidae
    - Linotetranidae
    - Paratydeidae
    - Trombidiidae
    - Caeculidae
  - Mesostigmata
    - Zerconidae
    - Trachytidae
    - Phytoseidae
    - Ascidae
    - Hypoaspidae
    - Pachylaelaptidae
    - Rhodacaridae
  - Cryptostigmata[*]
    - Gymnodamaeidae
      - *Jacotella* sp.
      - *Gymnodamaeus* sp.
    - Damaeidae[**]
      - Genus 1 sp. 3
      - Genus 1 sp. 6
      - Genus 2 sp. 5
      - Genus 5 sp. 3
    - Eremaeidae
      - *Eremaeus stiktos* Higgins
      - *Eremaeus* sp. (two species)
    - Oribatulidae
      - *Scheloribates* sp.
      - *Hemileius* sp.
    - Liacaridae
      - *Liacarus* sp. nr.
    - Charassobatidae
      - *Ametroproctus* sp.
    - Cepheidae
      - *Eupterotegaeus* sp.

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[*] Cryptostigmatid identifications by R. A. Norton, State Univ. of New York, Syracuse Campus

[**] Genus and species numbers refer to Norton terminology.

Appendix L. TAXONOMID LIST OF SOIL MICROARTHROPODS COLLECTED FROM THE BREEZY POINT, SNOW VALLEY, AND NEGV STUDY PLOTS, 1973-74 (Continued)

Passalozetidae

Passalozetes sp.

Hermanniellidae

Hermanniella sp.

Palaeacaridae

Palaeacarus sp.

Cosmochthonoidea

Cosmochthonius sp.

Aphelacaridae

Aphelacarus sp.

Camisiidae

Camisia sp.

Ceratozetidae

Propelops sp.

Galumnidae

Philogalumna sp.

Tectocepheidae

Tectocepheus *sarekensis* Tragardh

GLOSSARY

(An underlined word in a definition implies that this word is defined in another part of this glossary).

AAH - Ambient air house; a greenhouse experiment to evaluate tree growth in which ambient air was drawn into the house by fans.

AAO - Ambient air outdoors; used in reference to the outdoor control in an experiment on tree growth.

Abscission - Act or process causing leaves or needles to detach from the stem and fall to the ground; it occurs following advanced oxidant injury to leaves.

Accumulated Oxidant Dose - The sum of all the hourly average concentrations of total oxidant for any specified period, e.g., a month or a growing season, expressed as micrograms per cubic meter -hours ($\mu g/m^3$ -hrs).

Agar Media - A gelatinous nutrient substrate for growing microorganisms in the laboratory.

Alluvial - Deposited by running water, as soil material deposited during a flood.

Ambient Air - Air surrounding a given location; the outside air.

APCD - Air pollution control district, a county agency.

Attack - The point on a tree where the female bark beetle (Dendroctonus spp.) bores through the bark to feed and begin egg laying.

Available Water Storage Capacity - The total amount of water which a soil is capable of holding and which the plants can use.

Background Concentration (of ozone) - The world-wide background or natural concentration of tropospheric ozone injected downward from the stratosphere or formed by photochemical reactions in the troposphere; generally considered to be 59 $\mu g/m^3$ (0.03 ppm).

Basal Area - The area of cross section of a tree, expressed in square meters, and referring to the section at breast height.

Basal Fire Scars - Area of charred wood at the base of a living tree caused by a wildfire.

Bioindicator - Biological organisms which have specific sensitivity to a single pollutant and thus are useful as indicators for the presence of that pollutant.

Biomass - The total quantity at a given time of living organisms of one or more species per unit of space (species biomass), or of all the species in a community (community biomass).

Bole - The trunk or stem of a tree.

Bolt - A relatively small cylindrical section cut from the stem of a tree.

Branch Order - The arrangement of branches on a tree. The following terms are used to identify branches according to their order: main stem is referred to as the leader; any branch growing out of the leader is a first order branch; any branch growing out of a first order branch is a second order branch; any branch growing out of a second order branch is a third order branch, etc.

Cation - An ion which is positively charged in solution; typical cations in soils are potassium, sodium, calcium and magnesium (K^+, Na^+, Ca^{++}, and Mg^{++}).

Chlorotic Mottle - Irregular, diffuse patterns of yellow areas interspersed with normal green tissue.

Climax - Vegetation existing in a relatively stable equilibrium with its environment and with good reproduction of the dominant plants.

Codominant - Trees that share dominance of the canopy of a forest stand.

Colluvial - Deposited at least in part as a result of gravitational movement of material; occurs at the base of slopes and is sometimes stony or rubbly.

Colonization - Spread of a fungus throughout a substrate.

Complement - See leaf complement and needle complement.

Conidial - Of or pertaining to conidia which are asexual spores of many fungi.

Cores - Cylindrical samples of wood removed from a tree with a tool known as an increment borer.

Cover - The ground area covered by the individuals of one species.

Crown - The portion of a tree containing limbs, branches and foliage.

Crown Drip - Liquid which falls to the ground under the crown of a tree or other plant during precipitation or dew-formation onto the crown.

Crumb Structure - Same as granular structure except that the soil aggregates are relatively porous; common in the surface of forested soils.

Damping-off - The lethal effect of certain fungi on germinating seeds or seedlings.

Data Form - A standardized form upon which a certain type of information is recorded, mostly in the field.

Data Set - An identifiable complete unit of information composed of several individual entries.

DBH - Diameter of the trunk of a tree measured at breast height above the ground surface.

Debug (. . .computer program) - The identification and elimination of problematical errors in a computer program so that the computer may perform the intended functions.

Density - Number of individuals per unit area.

Dilution Plating - A known weight of humus or mineral soil is suspended and diluted in sterile distilled water; a portion of the suspension is swirled in water agar medium; developing fungal colonies are identified and counted.

Direct Plating - A known weight of litter or fermentation zone material is distributed evenly over the surface of water agar medium; developing fungal colonies are identified and counted.

Dose - A measured concentration of a toxicant for a known duration of time to which vegetation is exposed.

Duff - A collective term that includes the litter layer (fresh or slightly altered organic matter), fermentation layer (partially decomposed organic matter), and humus layer (amorphous organic matter) of the soil.

Eclosion - The emergence of the adult insect from the pupa or the act or process of hatching from the egg.

Ecosystem - A level of biological organization that includes the total array of plant and animal life in an environment and also the matter which cycles through the system and the energy used to power the system

Egg Niche - A small notch chewed by the adult bark beetle in the side of a gallery into which an egg is deposited.

Epidemiology - The study of spread or increase of disease.

Exchangeable Cation - A cation which is held mainly by the colloidal portion of the soil (clay and organic matter) which is not soluble in pure water but is easily exchanged with the cation of a neutral salt solution.

FAH - Filtered air house; used in reference to the greenhouse treatment in an experiment on tree growth in which filtered air (ozone removed) was forced into the house by fans.

Fascicle - A bundle of 1-5 needle leaves all originating from a common growth point; a characteristic of the foliage of pine trees.

Forest Floor - All dead vegetable matter or organic matter resting on the surface of the mineral soil, including leaves, branches, needles and humus not incorporated into the mineral soil; under forest vegetation.

Frass - A combination of boring dust and excrement or feces produced by feeding insects.

Gallery (length) - The tunnel created by adult bark beetles as they feed and deposit eggs in the phloem layer of a tree.

Granular Structure - Soil aggregates generally spheroidal in shape and less than 10 mm in diameter and relatively nonporous.

Gruss - Any rock that is granulated but not decomposed by weathering. Partially weathered granitic rocks are often gruss.

Herbaceous - Refers to plants that die back to the ground each year; for example, grasses and forbs are distinct from shrubs and trees in this regard.

Host - The plant, or animal, on, or in which a parasite exist

Human Welfare Effects - Includes, but is not limited to, effects on soils, water, crops, vegetation, man-made materials, animals, wildlife, weather, visibility, and climate, damage to and deterioration of property, and hazards to transportation, as well as effects on economic values and on personal comfort and well-being. (Clean Air Act, 1970).

Hypha - One of many cellular filaments making up the thallus of a fungus.

Importance Value - A measure of the degree to which a species occurs in a vegetation type and exerts influence on the microclimate of the type.

Inclusion Type - This refers to images in the x-rays of the bark samples that are categorized by form and developmental stage of the insect inclusions. There are six categories used in this study.

Infection - Establishment of a physiological relationship between a host and pathogen.

Instar - The period or stage between molts in the larva, numbered to designate the various periods; e.g., the first instar is the stage between the egg and the first molt, etc.

Internode - The portion of a woody stem produced in a single growing season.

Isolate - The product of culturing a small portion of a microorganism to yield a new individual.

Lachrymator - An atmospheric chemical compound which induces tears to run from the human eyes, and possibly from the eyes of various animals.

Larva - The young individuals in an insect population, which are due to undergo changes in their structural form.

Larval Mine - The small tunnels created by bark beetle larvae as they feed in the phloem or bark of a tree, generally perpendicular to the parent adult gallery.

Leaf Complement - A subjective evaluation of numbers of leaves present on all living branches of an oak tree as average, or less than average, for the stand.

Life Table - Similar to the actuarial tables kept by life insurance companies for humans. As adapted for insects, it is a convenient method to account for mortality during each developmental stage of an insect.

Line Interception Method - The sampling of vegetation by recording the plants intercepted by a measured line placed close to the ground, or by vertical projection on the line.

Loam - A textural class of soil containing 7 to 27 percent clay, 28 to 50 percent silt, and 23 to 52 percent sand.

Main Leader - The central trunk of a tree, usually refers to the youngest or tip portion.

Metamorphic Rock - Rock formed from pre-existing rock by mineralogical, chemical and structural alteration due to geologic processes originating within the earth.

Mesoscale Meteorological Patterns - A scale of observation of meteorological elements, namely winds and temperatures, which is intermediate between very local observations such as up-canyon or down-canyon breezes in a single canyon and the synoptic scale observations describing conditions over a broad area like the southwestern United States. The density of observing stations for mesoscale interpretation is typically 50 miles apart.

Micrograms Per Cubic Meter, μg/m^3-A measure of the concentration of a pollutant in micrograms per cubic meter of air at standard temperature and pressure.

Minimum Moisture Content - Measured soil water content at the driest period of the year; corresponds approximately to permanent wilting point.

Mixed Brood - A situation in bark beetle infested trees in which more than one species of bark beetle offspring is present in the same tree.

Model - A description of the system which it represents.

Molt - The process of certain organisms shedding their outer covering, to be succeeded by new growth.

Mortality - A standing tree whose current year buds are dead; a coniferous tree may be defoliated without being dead.

Needle Complement - The total number of needle fascicles retained on each branch internode, which were formed in any one growing season.

Needle Injury Score - The score or index is the sum of individual ratings for chlorotic mottle, necrosis and abscission, each on a scale of 0 to 4. The score, or index, may be as high as 12 for a single annual needle complement. Scores for current and one-year-old needle complements are often added together; this scoring procedure is adequate for seedlings and small saplings only.

Necrosis - An advanced stage of tissue injury indicated by brown, dead tissue, involving all or parts of a leaf or needle; necrosis develops following chlorotic mottle, especially in older leaf tissues.

Oviposition - the act of depositing eggs.

Oxidant Air Pollutants - Gas phase molecules and compounds capable of oxidizing a reference substance, namely the liberation of iodine from potassium iodide solutions; these include ozone (more than 90 percent) and smaller amounts of nitrogen dioxide and peroxyacetyl nitrate and its homologs, e.g., propionyl and butyrl.

Paradigm - The basic pattern underlying the functioning of a system.

Parameter - A characteristic which can be easily quantified.

Parasitoid - An insect, generally a wasp or fly, which lays its own eggs on the eggs, larvae, or adults of other species of insects (hosts) so that the larvae may develop by feeding within or upon the body of the host.

Particle Size Distribution - See soil texture.

Pathogen - Organism capable of causing disease.

Pathogen Type - An organism, not usually considered a pathogen, which behaves like a pathogen under special circumstances.

Pathophysiology - The altered metabolic state of pathogen infected, or toxicant injured tissues.

Permanent Wilting Point - The soil moisture content at or below which plants can absorb water only very slowly or not at all; sunflower used as a test plant wilts and does not recover over night.

pH (soil) - A measure of the acidity or alkalinity of a soil expressed as the negative logarithm of the hydrogen-ion activity of the soil. The general range of soil pH is 4.0 (very strongly acid), 7.0 (neutral), 10.0 (strongly alkaline).

Phenology - The study of the time of appearance of characteristic periodic events in the life cycles of organisms in nature.

Phloem - The complex tissue of higher plants which forms a spongy layer between the protective outer layer and the inner structurally supportive portion. Its function is to transport food materials.

Photosynthetic Capacity - The ability of a plant to convert inorganic carbon in the air, from carbon dioxide, into organic carbon molecules in a given environment.

Phytotoxicant - Any chemical agent that causes injury to plants.

Pitch Tube - A small resinous tube projecting from the bark of a tree as a result of a beetle boring into the tree. A successful attack is indicated by frass in the resin while an unsuccessful attack produces a pitch tube without frass.

Plot - An area of land surface within which vegetation, soil, and animal life is periodically inventoried and studied for determining dynamic interactions among them. In this study, 18 plots were delineated on the ground during 1972 in the San Bernardino Mountains. The range of individual plot area sizes runs from 0.2 ha to 1.2 ha.

Pollinator - An organism, usually an insect, which carries pollen from one flower to another.

ppb - Parts by weight, or volume, of pollutant per billion parts by volume of air (usually refers to volume of pollutant if not so stated).

pphm - Parts by weight, or volume, of pollutant per hundred million parts by volume of air (usually refers to volume of pollutant if not so stated).

ppm - Parts by weight, or volume, of pollutant per million parts by volume of air; it usually refers to volume of pollutant if not so stated.

Pupal Cell - A cavity in the bark or phloem created during the final feeding of the larvae of bark beetles and in which the larvae go into a non-feeding, and often immobile, transformed stage of development.

Quadrat - A sampling area 0.1 m square used to sample herbaceous vegetation.

r-Value - The coefficient of correlation between a dependent and an independent variable. When there is no association between two variables, the correlation coefficient is 0; when there is perfect positive association, the coefficient is +1; and when there is perfect negative association, the coefficient is -1.

Rearing - Raising insects in the laboratory. This allows insects to complete their development to the adult stage before being collected and identified. Immature insects are difficult to identify so this is an important procedure.

Rearing Carton - A paper ice cream carton with a glass vial attached to the lid. It is used to capture insects as they emerge from the bark samples. The insects are attracted to light and fall into the glass vial.

Ring Count - A method used to determine tree age by counting annual growth rings of the bole, usually at DBH.

Sanitation Salvage - A forest management technique with the objective of periodic removal of ponderosa and Jeffrey pines judged to have reduced vigor and to be more susceptible to fatal attack by bark beetles; the selection and cutting process is repeated every 10 years.

Sapling - A tree that is more than one meter in height and less than 10 cm in diameter at breast height.

Saprophyte - An organism utilizing an organic source of food which is dead.

Senescence - The combined processes by which leaves or needles on a tree age, and undergo abscission.

Simulation - The process of using a dynamic model on an electronic computer to mimic the functioning of a system or process by repeated step-by-step solution of the equations describing the system.

Soil Bulk Density - The mass of dry soil per unit volume of soil in its natural state which may be moist at the time the volume is determined.

Soil Core - A cylindrical sample of soil, usually circular in horizontal cross section.

Soil-dilution Assay - See dilution plating.

Soil Moisture Regime - The variation of soil moisture content throughout the soil through an entire year.

Soil Texture - A classification of soil material based upon particle size distribution of the mineral grains in the soil, the relative proportions of sand, silt, clay and gravel.

South Coast Air Basin (SCAB) - One of the five principal airsheds (atmospheric basins) in the State of California and partially located within the six counties of Santa Barbara, Ventura, Los Angeles, San Bernardino, Orange and Riverside.

Species Composition - The relative percentage of the total number of individuals in a vegetation type represented by a certain species.

Species Dominance - The degree of influence a species exerts over a vegetation type.

Spore - A reproductive body capable of developing into a new individual fungus thallus.

Subsoil - A general term for soil material from about 25 to 100 cm depth below the surface, although these depths may vary considerably.

Succession - The replacement of one vegetation type by another.

Synoptic meteorological patterns - Typically a description of air pressure patterns at the surface and at higher elevations over a broad area (see mesoscale meteorological patterns). Synoptic scale stations are usually more than 100 miles apart, e.g., Los Angeles, California and Tonapah, Nevada.

System - A set of elements together with relations among the elements and among their states.

Systems Ecology - The application of the philosophy and techniques of systems analysis to ecological problems.

Temperature Inversion - When air temperature decreases from the surface up at a rate greater than 5.5 F per 1,000 ft. or 1.0 C per 100 m, there is pronounced vertical mixing. But if the temperature increases with height, vertical air movements are suppressed. This temperature profile is "inverted" from the normal condition and it is a temperature inversion. Air pollutants are trapped near the ground by temperature inversions.

Terminal Shoot - The uppermost section of the main leader of a tree.

Thallus - The vegetative structures comprising body of lower plant forms, for example, fungi.

Troposphere - The layer of air extending 7 miles above the earth's surface and containing 80 percent of the total atmospheric mass.

Vegetation Type - A plant community of definite floristic composition, presenting a uniform physiognomy and growing in uniform habitat conditions.

Volumetric Water Content - The volume water content of soil per unit volume of soil; expressed as percent by volume.

Water Balance - A complete accounting of the soil moisture regime; water gains and losses from, and to, the atmosphere, and losses to runoff and deep percolation into the groundwater system.